AD-A241 272

PL-TR-91-2175

INSTRUMENTATION, CONTROL AND COMMUNICATION SYSTEMS FOR SOUNDING ROCKETS AND SHUTTLE-BORNE EXPERIMENTS

J. SPENCER ROCHEFORT
LAWRENCE J. O'CONNOR
RAIMUNDAS SUKYS
NORMAN C. POIRIER
RICHARD L. MORIN

Northeastern University
Electronics Research Laboratory
360 Huntington Avenue
Boston, MA 02115

2 July 1991

Final Report
1 July 1987-31 March 1991

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

PHILLIPS LABORATORY
AIR FORCE SYSTEMS COMMAND
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

"This technical report has been reviewed and is approved for publication"

WILLARD F. THORN
Contract Manager

for RUSSELL G. STEEVES, Chief
Development & Verification Branch

FOR THE COMMANDER

C. NEALON STARK, Director
Aerospace Engineering Division

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify OL-AA/PL/IMA, Hanscom AFB, MA 01731-5000. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
2 July 1991

3. REPORT TYPE AND DATES COVERED
Final (1 July 1987-31 March 1991)

4. TITLE AND SUBTITLE
Instrumentation, Control and Communication Systems for Sounding Rockets and Shuttle-Borne Experiments

5. FUNDING NUMBERS
PE 62101F
PR 7659 TA 04 WU BM
Contract F19628-87-C-0128

6. AUTHOR(S)
J. Spencer Rochefort
Lawrence J. O'Connor
Raimundas Sukys
Norman C. Poirier
Richard L. Morin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Northeastern University
Electronics Research Laboratory
360 Huntington Avenue
Boston, MA 02115

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Phillips Laboratory
Hanscom AFB, MA 01731-5000

Contract Manager: Willard F. Thorn/LCT

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
PL-TR-91-2175

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words) This report deals with the design, development, fabrication, analysis and field support of signal processing, control systems and telemetry systems for space vehicles. Sounding rocket programs discussed include BEAR, COLDR, LIFE AND SPEAR I. Shuttle-borne programs include IMPS, IBSS/CIV and GAS/VIPER. Brief studies were made of airborne optical disk recording systems and packet telemetry. A telemetry system for vibration and shock testing and electro-mechanical release systems were also developed. PL (formerly GL) scientists were provided consultation and assistance in monitoring the EXCEDE-III and SPIRIT-II program.

14. SUBJECT TERMS
Sounding rocket
Shuttle-borne experiments
BEAR, HPB, IBSS/CIV, IMPS
LIFE
SPEAR
Optical recorders
Packet TLM
EXCEDE III
SPIRIT II
GAS/VIPER

15. NUMBER OF PAGES
144

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

- TABLE OF CONTENTS -

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

1.0 INTRODUCTION

This contract has involved the study, analysis, development and field support of instrumentation, signal processing units, control systems and telemetry systems for sounding rockets and shuttle-borne experiments. Some of the work reported here began during two earlier contracts: AF19628-83-C-0037 which covered the period 4 December 1982 through 31 December 1986, and AF19628-81-C-0029 which covered the period 16 February 1981 through 5 May 1987.

Section 2.0 is concerned with the sounding rocket programs COLDR, SPEAR I, BEAR, the BOOSTED ARIES and LIFE. Of these programs COLDR I, SPEAR I, BEAR and the BOOSTED ARIES were carried through successful launches, while COLDR II and LIFE will be carried over to the follow-on contract.

The BEAR program required the heaviest commitment of manpower and field support under the contract. The rocket carried an accelerator developed by the Los Alamos National Laboratory and produced the first neutral particle beam in space. The Electronics Research Laboratory (ERL) developed a substantial amount of on-board electronics and control circuitry and provided all telemetry and television air-to-ground transmission links.

Section 3.0 contains discussions of the shuttle programs IMPS, IBSS and GAS/VIPER. Of the three, IMPS was terminated due to funding problems and the other two will be carried over into the follow-on contract.

Studies, surveys and experimental development programs have been grouped into Section 4.0 under a Research and Development heading. The material treated in this section was not carried out in direct support of any single program, but was intended to broaden knowledge and develop hardware systems which could be used on future rockets.

Section 5.0 contains a discussion of ERL's work in providing consultation and assistance to AFGL scientists in monitoring work carried out by industry in integrating the EXCEDE III and SPIRIT-II programs.

Section 6.0 contains a tabulation of field support, launch dates and travel required to support the programs discussed in prior sections.

2.0 ROCKET PROGRAMS

2.1 COLDR

The primary objective of the Conductivity of the Lower D-Region (COLDR) program is to measure the total conductivity of the atmosphere between 40 and 80 km altitude under quiet and disturbed conditions in order to provide necessary data for theoretical models of the VLF/ELF propagation processes. Specifically, the experiment measures the electron, positive ion, and negative ion concentrations and the mass distributions. A high altitude parachute is deployed prior to apogee in order to slow the payload velocity and orient the payload with its nose foremost. Measurements are taken immediately prior to apogee and during the parachuted descent phase until approximately 40 km.

Originally two payloads from the Solar Proton Event (SPE) program were allocated for COLDR. ERL personnel supported the COLDR-I launch at the Wallops Flight Facility (WFF), Virginia, where a Nike Orion boost vehicle was used to evaluate the unique concept of collecting data during slow descent. Recovery was not planned for this launch because a suitable recovery aircraft was not available. The second reconfigured SPE payload, designated COLDR-II was completed under this contract and is ready for integration testing. It is anticipated that a skyvan aircraft, capable of retrieving a 200 lb. payload will be used to recover COLDR-II.

2.1.1 Configuration

Figure 2.1.1 is the configuration drawing for the COLDR payload and shows the transition from the 12" diameter payload to a 9" nosecone section.

The payload is contained in a cylindrical shell with a gas release system (SF_6) in a split nose cone which is ejected in flight. The experiment control and support electronics, as well as the telemetry system, are located in separate sections aft of the experiment. The payload deceleration system is contained within a transition section aft of the payload. This system is energized by a gas piston that separates the experiment from the remainder of the payload and simultaneously deploys the parachute. Table 2.1.1 details the COLDR payload data.

2.1.2 COLDR-I

The COLDR-I payload was integrated and environmentally tested at the AFGL PVIF during July 1987. All tests were successfully completed and the field party arrived at the WFF on 3 August 1987. The payload was successfully launched on Friday, August 14, 1987, at 1229 hours on an azimuth of 135.5° and at an elevation of 84.2°. An apogee of 85.9 km was attained.

The telemetry system was a PCM/FM/FM S-band system consisting of a three watt transmitter at 2251.5 MHz. There were thirteen subcarrier oscillators modulating the transmitter. The subcarrier listings and assignments are shown following:

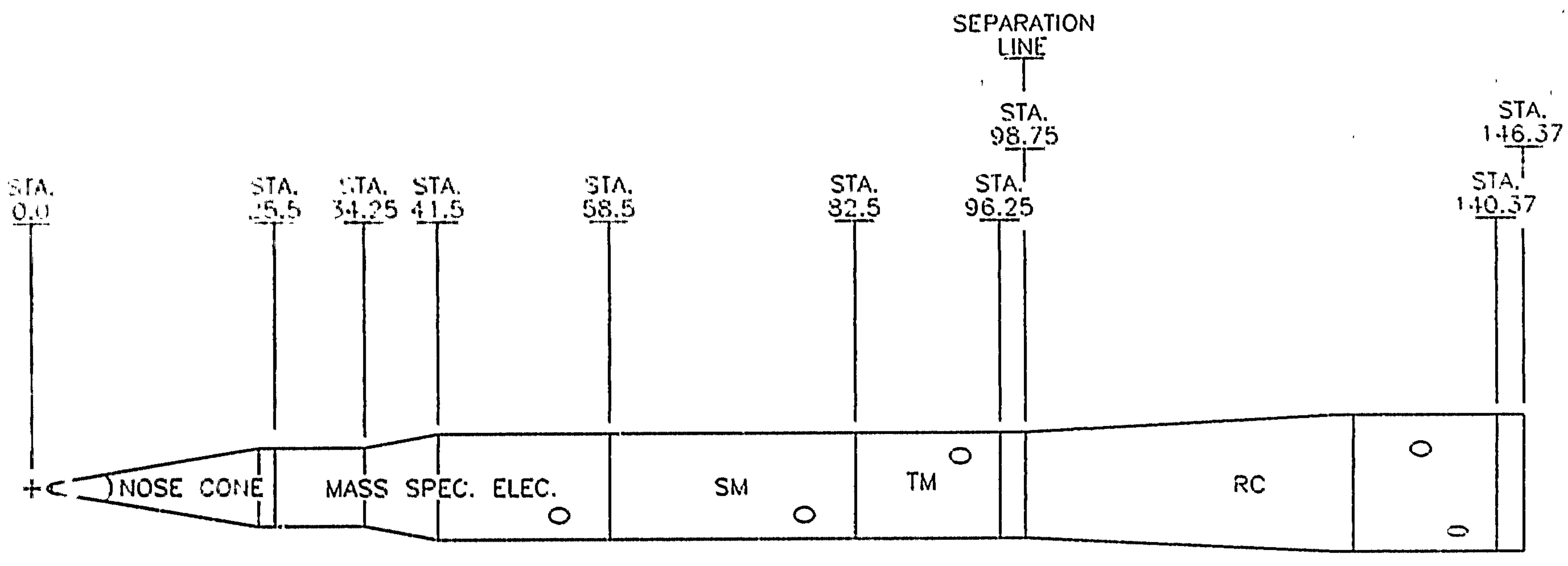


FIG. 2.1.1

COLDR CONFIGURATION

TABLE 2.1.1

COLDR DATA

PAYLOAD CONFIGURATION
- WEIGHT: 507.62 LBS.
- DIAMETER: 12 INCHES
- LENGTH: 146.37 INCHES

SCIENTIFIC EXPERIMENTS --- (SUPPLIERS)
- MASS SPECTROMETER - (AFGL)
- SF6 RELEASE - (AFGL)

SUPPORT SYSTEMS --- (SUPPLIERS)
- 2 MAGNETOMETERS ROLL, PITCH - (NU)
- COMMUTATOR - (NU)
- PRESSURE TRANSDUCER - (NU)
- LONGITUDINAL ACCELEROMETER - (NU)

RF SYSTEMS
- PCM/FM/FM TELEMETRY LINK:
  - 2251.5 MHZ 3 WATTS
- BEACON TRANSPONDER:
  - C-BAND, DOUBLE PULSED

PAYLOAD TIMING
- TIMERS, (REDUNDANT) MODEL 50 - (NU)

MECHANISMS
- TIP EJECT
- SEPARATION - PAYLOAD/VEHICLE
- CAP PULL - MASS SPECTROMETER

IRIG CHANNEL	FREQUENCY	DATA DESCRIPTION
21	165 kHz	Mass Spectrometer at 4 Kbps
20	124 kHz	Mass Spectrometer AG_1
19	93 kHz	Mass Spectrometer AG_2
18	70 kHz	Tradat Ranging at 3906 bps
17	52.5 kHz	Mass Spectrometer Analog Signal
16	40 kHz	Mass Spectrometer RF Signal
15	30 kHz	IRIG 1X60 RZ Commutator
12	10.5 kHz	Mass Spectrometer Front End Bias
11	7.35 kHz	Mass Spectrometer Q Bias
10	5.4 kHz	Mass Spectrometer ACC
9	3.9 kHz	Magnetometer Roll Axis
8	3.0 kHz	Magnetometer Pitch Axis
7	2.3 kHz	Accelerometer

Tracking was accomplished by the use of the Tradat Ranging System with a payload receiver at 550 MHz and a C-Band Radar Transponder, Model 302C.

The support section contained two payload timers, batteries, a two-axis magnetometer, a roll axis accelerometer, a pressure gauge and other monitoring systems.

2.1.3 COLDR-II

COLDR-II has a single link PCM/FM/FM S-band system utilizing a three watt transmitter. The subcarrier channels and assignments are as follows:

IRIG CHANNEL	FREQUENCY	DEVIATION	DESCRIPTION
21	165 kHz	158 kHz	MS PCM at 8 kbps
18	70 kHz	141 kHz	Tradat
15	30 kHz	6 kHz	1 x 60 Commutator
9	3.9 kHz	5 kHz	Spin Axis Magnetometer
8	3.0 kHz	5 kHz	Pitch Axis Magnetometer
7	2.3 kHz	5 kHz	Accelerometer

The COLDR-II support module contains two Model 2480 timers, batteries, control relays, a two-axis magnetometer, an accelerometer, power conditioning modules and controls for the gas release system (SF_6). As indicated previously, it is expected that integration and flight will be carried out under the follow-on contract.

2.2 SPEAR-I

2.2.1 Background

The SPEAR-I experiment was designed by Utah State University to study the collection of current from high voltage biased electrodes in ionosphere. Figure 2.2.1 shows the payload configuration. The primary instrumentation consisted of two spherical current collectors, a programmable high voltage power supply, and various current and voltage measuring devices. Supporting instruments included a Langmuir probe, visible spectrum photometers, a low light level television camera, a neutral pressure gauge, particle detectors and a plasma contactor. The payload also included an attitude control system, timers, a radar transponder,

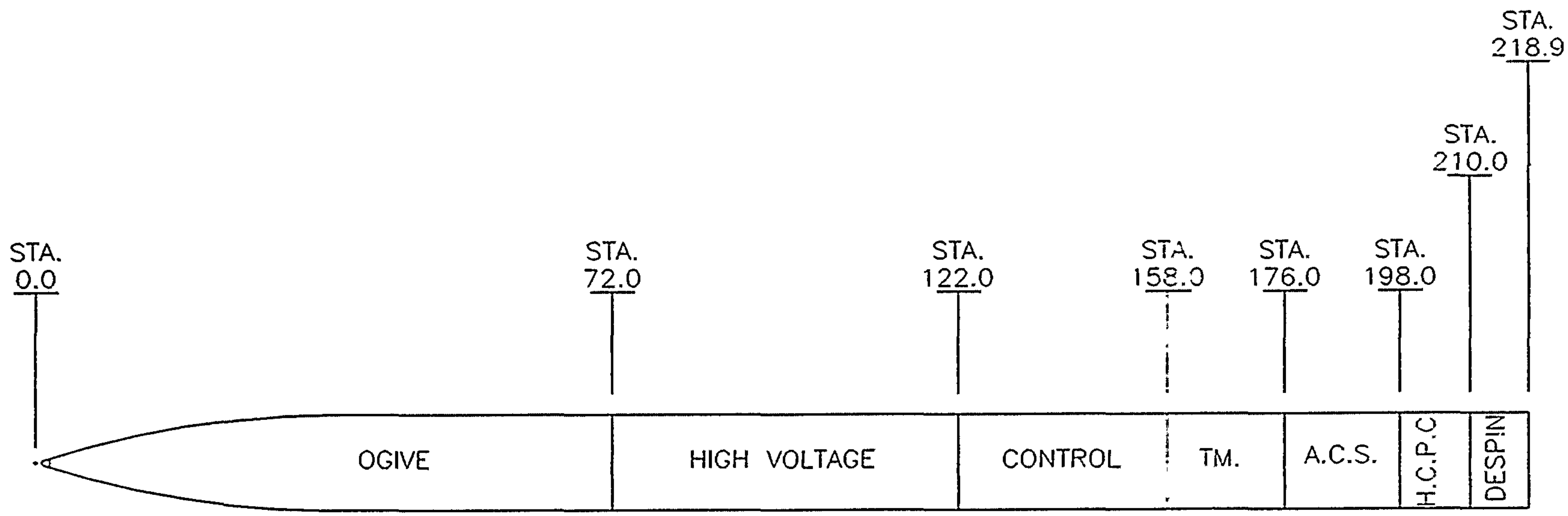


FIG. 2.2.1

SPEAR 1 CONFIGURATION

telemetry, power system, control and the other usual payload components. The experiment was launched on a Black Brant X rocket on December 13, 1987 from Wallops Flight Facility.

2.2.2 Support System

The initial work on SPEAR-I was started by ERL in May 1987 under sub-contract No. 87-526 from Utah State University. ERL provided the telemetry system, timers, batteries and power distribution, a rack structure and a wiring harness between the various systems interfacing with the ERL subsystem. Details are presented in Table 2.2.2. This work was completed in September 1987 and all effort was transferred to the subject contract (F19628-87-C-0128). Payload integration and testing was completed at the AFGL environmental facility during October 1987. Vacuum chamber testing at the Plumbrook Station located in Sundusky, Ohio was conducted during November 1987 to confirm payload operation under vacuum and to calibrate the systems for evaluation of flight results.

The telemetry consisted of a PCM/FM, FM/FM and video links transmitted over a single stripline antenna. The PCM encoder designed and constructed at ERL operated at 426 kbps in a NRZ-S format. The FM/FM system contained 12 subcarrier oscillators. Since many wide band signals were present a non-standard taper was employed to accommodate the resulting low modulation indexes of the subcarriers.

Due to the possible hostile environment created by high voltage transfers mechanical, instead of the usual electronic timers, were employed. However, the timing interval during

TABLE 2.2.2

SPEAR I PAYLOAD DATA

PAYLOAD CONFIGURATION

WEIGHT:	820 LBS.
DIAMETER:	17 INCHES
LENGTH:	258 INCHES

SCIENTIFIC EXPERIMENTS --- (SUPPLIERS)

CURRENT COLLECTOR SPHERES (2) - (USU)
NEUTRAL PRESSURE GAUGE - (U IOWA)
PHOTOMETERS (2) - (USU)
LANGMUIR PROBE - (USU)
PARTICLE DETECTOR - (U ALABAMA)
WAVE RECEIVER - (SYSTEMS UNLIMITED)
PLASMA CONTRACTOR - (SRI)

SUPPORT SYSTEMS --- (SUPPLIERS)

LOW LIGHT LEVEL TV - (USU)

RF SYSTEMS

PCM TELEMETRY LINK:

2279.5 MHz	2 WATTS	425 KBPS

FM TELEMETRY LINK:

2251.5 MHz	10 WATTS	WIDEBAND

VIDEO TELEMETRY LINK:

2215.5 MHz	10 WATTS

BEACON TRANSPONDER:

C-BAND, DOUBLE PULSED

PAYLOAD TIMING

RAYMOND ENGINEERING, MECHANICAL TIMERS

this flight exceeded the capabilities of these timers. Therefore, an additional timer, activated by pyrotechnic devices was used to provide the necessary timing functions during the latter part of the flight. SPEAR-I, A22.703, was launched from the Wallops Flight Facility in VA on Dec. 13, 1987. All ERL support systems performed flawlessly.

2.3 BEAR

2.3.1 Background

The Beam Experiments Aboard a Rocket (BEAR) project was a Strategic Defense Initiative Office program initiated as part of its Directed Energy Weapon effort. The goal of the BEAR project was to adapt and launch a Los Alamos National Laboratory developed neutral particle beam accelerator aboard a sounding rocket. This effort would develop spaceworthy hardware, test it in flight and develop a data base on the engineering and phenomenological aspects of operating an accelerator in a space environment.

2.3.2 Overview

The 38-inch diameter BEAR payload configuration is presented in Figure 2.3.2. As indicated, the telemetry/physics section was located forward of the accelerator/beam diagnostic section, and below the nosecone which housed the attitude control and recovery. The boost control system (BCS) was autonomous with no electrical connection to the remainder of the payload. Particulars of the payload sub-systems are listed in Table 2.3.2 with details discussed in the following sections.

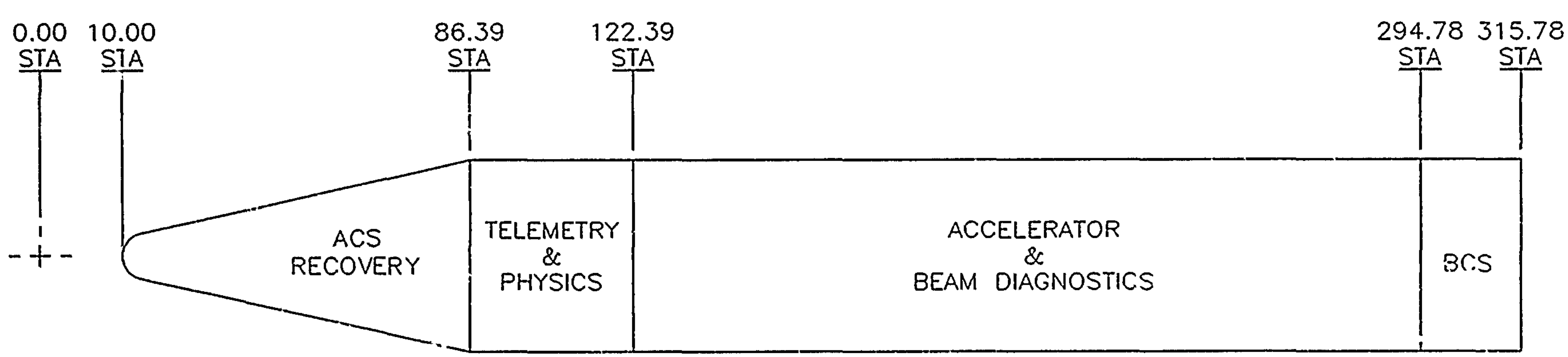


FIG. 2.3.2

BEAR CONFIGURATION

TABLE 2.3.2

BEAR PAYLOAD DATA

PAYLOAD CONFIGURATION

- WEIGHT: 3408 LBS
- DIAMETER: 44 INCHES
- LENGTH: 306 INCHES

SCIENTIFIC EXPERIMENTS --- (SUPPLIERS)

- ELECTROSTATIC ANALYZER (SCIENCE APPLICATIONS CORP.)
- HIGH IMPEDANCE VOLTMETER PROBE (NRL/WENTWORTH)
- 2 PLASMA WAVE RECEIVERS (NRL/[illegible]TZMAN)
- 4 LANGMUIR PROBES (NRL, HOUS[illegible] BD SECTION)

SUPPORT SYSTEMS --- (SUPPLIERS)

- FLIGHT RECORDER (N.U.)
- 3 AXIS MAGNETOMETER (N.U.)
- 3 AXIS ACCELEROMETER (NU)
- PRESSURE TRANSDUCER (NU)
- 14 THERMISTORS (NU)
- REGULATOR, 5V (NU)
- 3 TM REGULATORS (NU)
- 2 PCM ENCODERS (NU)
- DIGITAL MULTIPLEXER (NU)

RF SYSTEMS

PCM TELEMETRY LINKS:

(1)	2269.5 MHZ,	8 WATTS,	800KB/S,	NU/PHYSICS
(2)	2241.5 MHZ,	3 WATTS,	63KB/S	ACCEL PRIME
(3)	2251.5 MHZ,	8 WATTS,	63KB/S	ACCEL/BACKUP
(6)	2259.5 MHZ,	8 WATTS,	64KB/S	BCS

FM TELEMETRY LINK:

(5)	2279.5 MHZ,	8 WATTS,	3.3MHZ BW	PWR WIDEBAND

VIDEO TELEMETRY LINKS:

(4)	2215.5 MHZ,	10 WATTS,		CAMERA 1
(7)	2233.5 MHZ,	10 WATTS.		CAMERA 2

BEACON TRANSPONDER:

(2 EA) C-BAND, DOUBLE PULSE

PAYLOAD TIMING

NU APCAM, REDUNDANT CONTROLLERS, 12 CONTROL RELAY MODULES
RAYMOND ENGINEERING, MECHANICAL TIMER

MECHANISMS

DOOR EJECT	- 4 DOOR
BOOM DEPLOY	- 2 PWR, HIV
SEPARATION	- PAYLOAD/VEHICLE, BD SKIN
PROBE DEPLOY	- 4 LP, 3 SSD
SENSOR EJECT	- 2 PWR, HIV

2.3.3 Telemetry/Physics Section Configuration

The 44-inch diameter Telemetry/Physics (TP) section was 36-inches long with external telemetry and beacon antennas, four ejectable doors, an access door and four umbilical connectors. Internally, a 0.50-inch thick magnesium deck plate had components mounted on both sides. Figure 2.3.3 identifies the location of the four sensors and their related electronics on the top side of the TP deck.

Plasma Wave Receiver (PWR) Probes are located at 0^{o} and 180^{o}; the High Impedance Voltmeter Probe (HIV) assembly at 270^{o}; and the Electrostatic Analyzer (ESA) housing behind the ejectable door at 90^{o}.

An internal door system was incorporated in the section in order to restore the integrity of the exterior skin after the booms are ejected. The final configuration consisted of three individual hinge mechanisms in lieu of the original design which required timing pulses and a relatively complex release mechanism. Telemetry and support components were mounted on the underside of the same deck, and on both sides of an ancillary extension deck.

Venting and outgassing were identified as concerns at the LANL meeting on 18 October 1988. This contractor was tasked with providing positive venting of all enclosures in the TP section and providing data for analysis to LANL. A report including a calculated volume of both sections of the TP, the area of ejected doors and potential sources of outgassing was formulated. The recommendation was a dry nitrogen purge

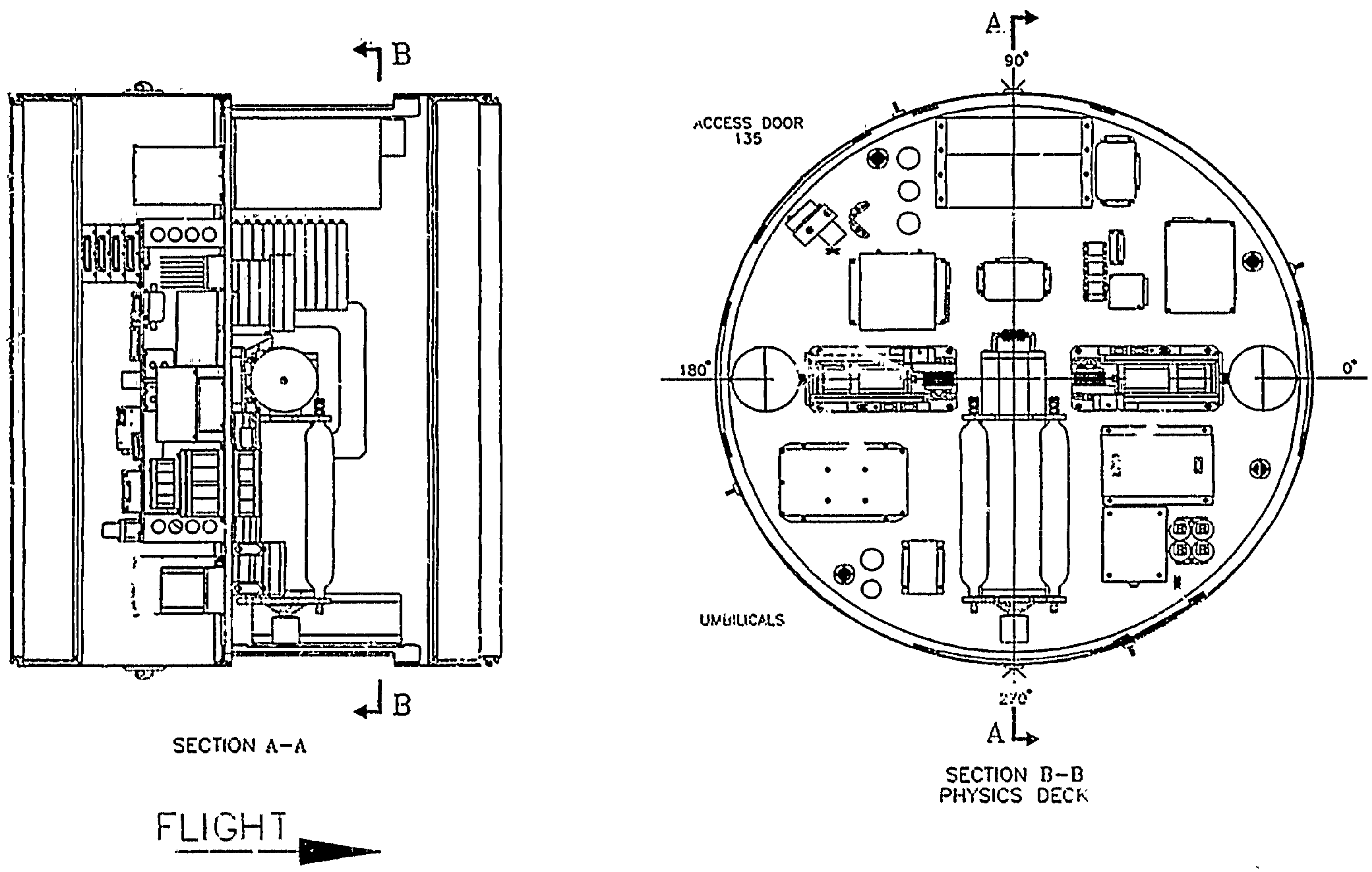


FIG. 2.3.3

BEAR TP CONFIGURATION

providing a minimum of six volume changes on the pad prior to the launch. A spare coax pin in the RF umbilical connector was utilized to interface the 1/4" tubing required for the purge. This solution inherently resolved the fly-away requirement for the purge line when the umbilical connector is released.

2.3.4 Power Systems

Power systems for the BEAR TP section included nicad battery packs, DC/DC converters, switching relays and monitor circuits. The power block diagram is included as Figure 2.3.4 where the "K" designations indicate internal/external power transfer relays and the control relay modules are defined as "CR" blocks. All relays were operated by the payload controllers and monitored on the TP telemetry link. Specific battery allocations for the TP section as well as the normal operating current for each of the sub-systems are presented as follows:

ID	VOLTS	AH	ASSIGNMENT	AMPS
B1	28.8	2.2	EXPERIMENTS	
			ESA SW	0.8
			PWR	0.7
			HIV	0.1
			LP	0.2
			LFPWR	.13
			BOOM #3	.68
B2	28.8	1.2	CONTROLLER 1	0.4
			INSTRUMENTATION	.12
			VIB ACCELEROMETERS	0.4
B3	28.8	7.0	TRANSMITTER 1	1.7
			TRANSMITTER 2	1.6
			BEACON	1.0
			CONVERTER 2	.14
			CONVERTER 3	.31

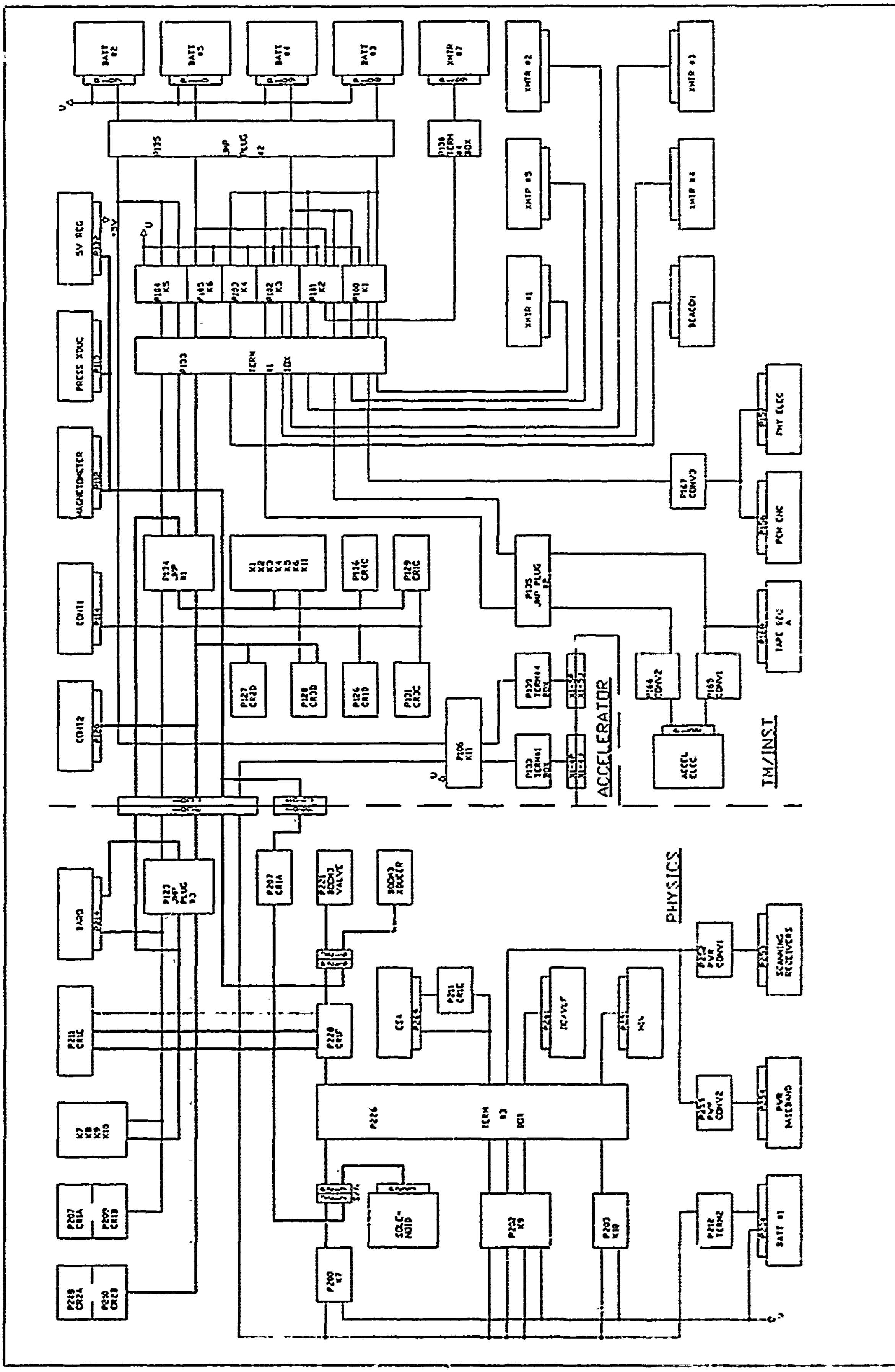


FIG. 2.3.4 POWER BLOCK DIAGRAM

B4	28.8	4.0	TRANSMITTER 3	1.5
			TRANSMITTER 5	1.7
			CONVERTER 1	.40
			RECORDER	.24
B5	28.8	7.0	TRANSMITTER 4	2.62
			CONTROLLER 2	0.2
			TRANSMITTER 7	2.51

In addition to the TP batteries, modified nicad battery packs were supplied by ERL to the Los Alamos National Laboratory (LANL) for accelerator and beam diagnostic power. Standard cells and packaging techniques were used, but unique voltages were required for the ion source and the radio frequency quadrupole. Two standard packages wired in series with the appropriate number of cells were utilized in these applications. In addition, mesh enclosures were designed for these seven batteries to meet the accelerator section shielding requirements.

Data from the BEAR launch indicate that all pre-launch and in-flight switching was normal and battery discharge characteristics were as anticipated.

2.3.5 Control Systems

The TP control system consisted of two electronic controllers, a mechanical timer and several control relay modules. A block diagram is presented as Figure 2.3.5 indicating that six of the control relay modules (designated CR) and both controllers were located on the TM/instrumentation side of the deck. The remaining control relay modules and the mechanical timer, assessable through an access door, were mounted on the physics side of the deck

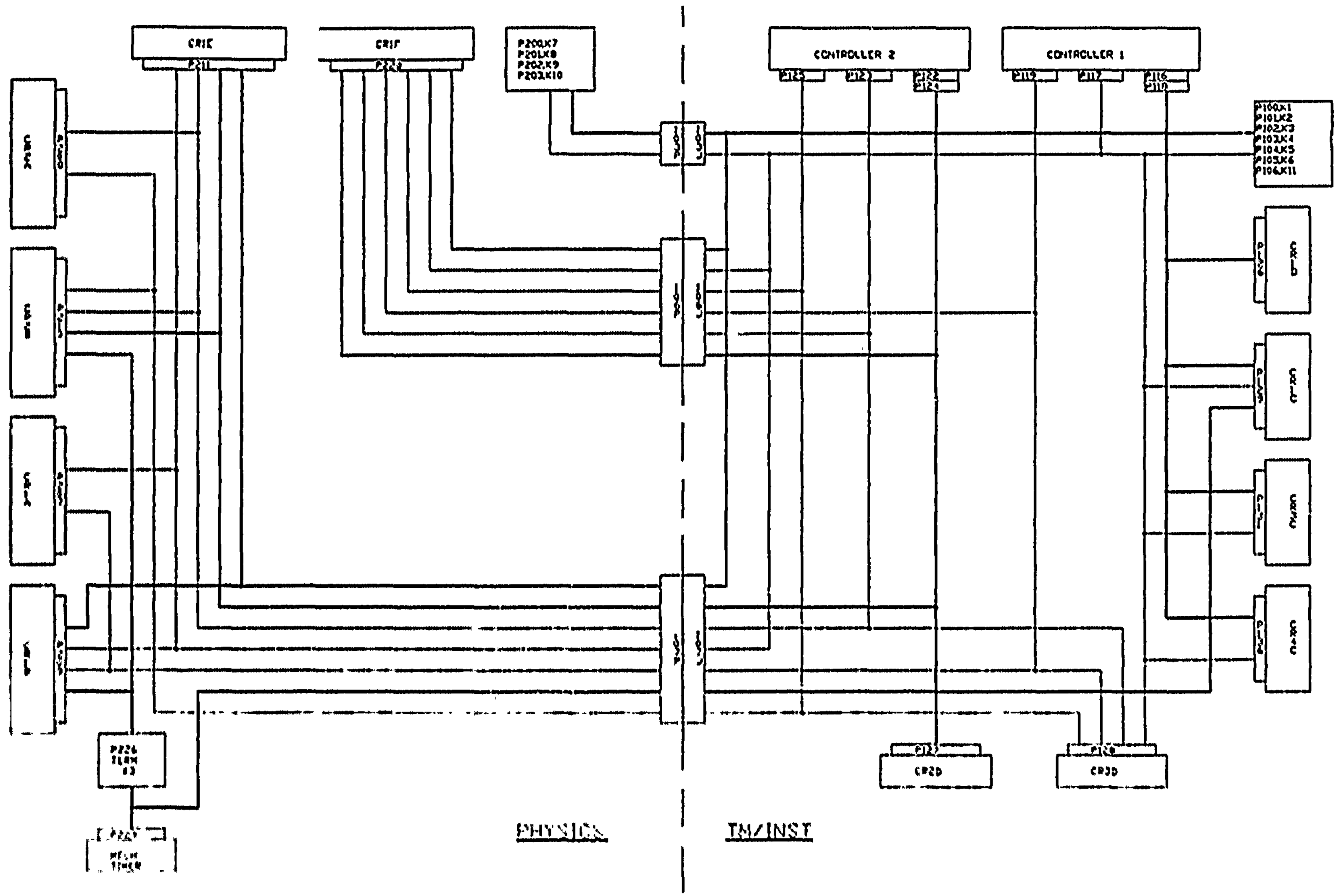


FIG. 2.3.5

CONTROL BLOCK DIAGRAM

plate. The BEAR controllers were configured with single digital output and digital input boards for 64-function switching capability. Controller #1 operated all pre-launch and flight functions and Controller #2 provided redundancy for critical flight events. Ground support computers allow the operator to access all payload functions through an RS-232 serial communication link. Individual function control and monitor is available as well as pre-programmed test and flight sequences.

Relay control lines from the digital output board consist of high-current latch drivers to external payload relays. Corresponding relay monitor lines are interfaced to the controller digital input board. Both the power distribution relays and the control relays are operated by the controllers. Controller specifics are presented in the flight hardware section of this report.

One second before the accelerator sequence began (T+100 seconds) the redundant controllers actuated a solenoid mechanism to start the mechanical timer. The mechanical timer was implemented due to the possible susceptibility of the electronic controllers during beam operation. Three cam actuated switches provide:

1. Ejection of both PWR booms (close internal doors),
2. Ejection of the HIV boom (close internal door), and
3. All systems off command to accelerator.

During the BEAR launch both controllers and the mechanical timer functioned normally. The controllers were manually started at T-15^ seconds, accomplished a self-test and initialization sequen , switched systems internal (except for the HIV which was switched external) and armed the pyro circuits prior to T=0. Telemetry monitors indicate all accelerator commands, physics experiment switching and pyro functions occurred at the pre-programmed times.

The mechanical timer successfully ejected the three booms in the TP section and initialized the accelerator turn-off sequence. Due to the inherent setting accuracy of the cams in the mechanical timer, the following discrepancies, within the accepted tolerance, are noted:

	Programmed Time	Actual Time
Boom 1 & 2 eject (PWR)	380 sec.	381 sec.
Boom 3 eject (HIV)	381 sec.	382.5 sec.
Accelerator ASO	390 sec.	391 sec.

2.3.6 Pyro Functions

Figure 2.3.6 is a block diagram of the BEAR pyro system, indicating pyro actuated mechanisms in both the TP section and in the accelerator/beam diagnostic section. As indicated 9.6-volt nicad batteries, electromechanical arming relays, safe/arm connectors and independent control relays were provided for each bridgewire, providing totally redundant systems. The following is a list of the pyro functions and the actuating devices:

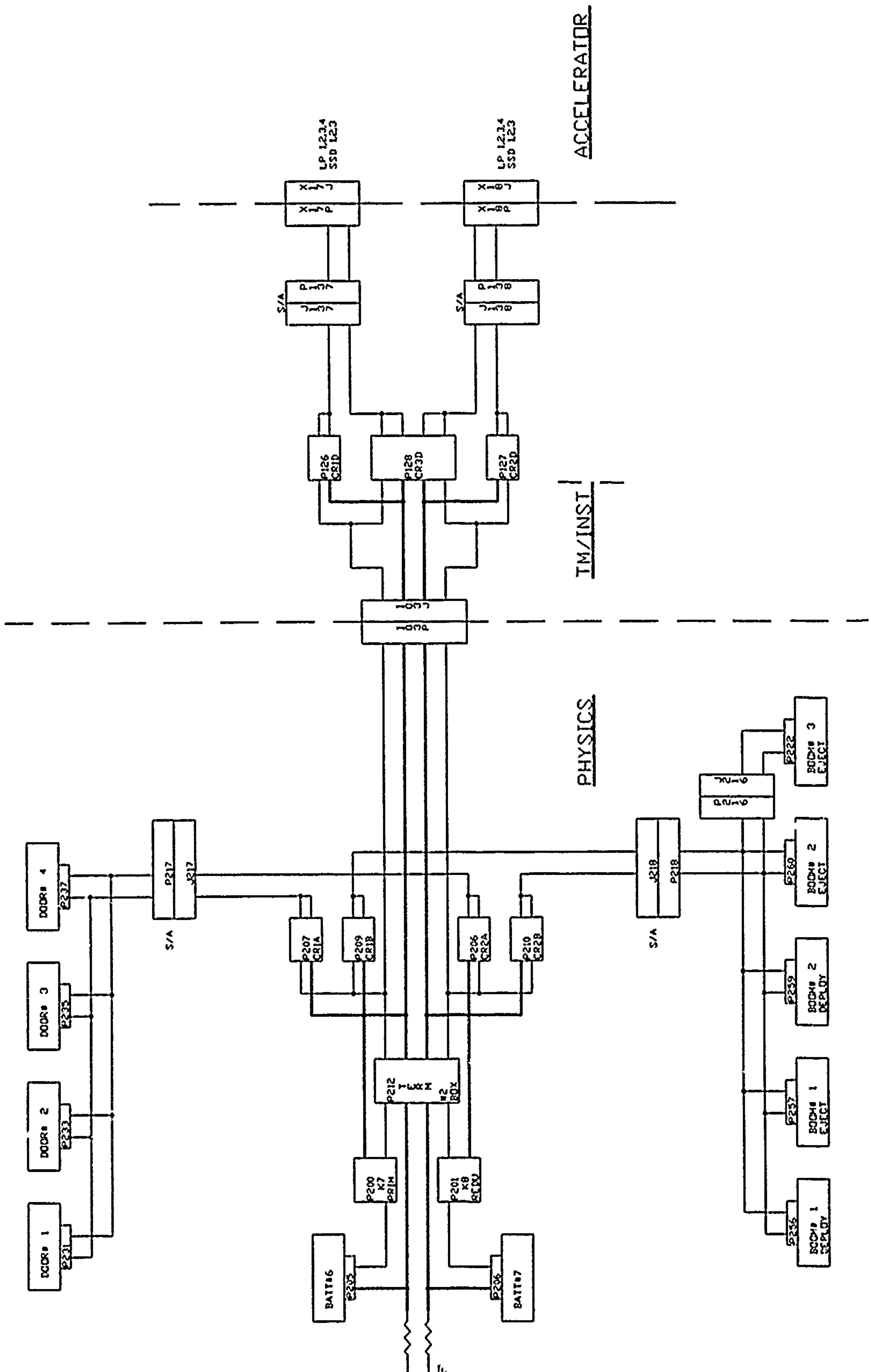


FIG. 2.3.6

PYRO BLOCK DIAGRAM

FUNCTION	DEVICE	TYPE	QUANTITY
DOOR #1 EJECT	GUILLOTINE	5801	2
DOOR #2 EJECT	GUILLOTINE	5801	2
DOOR #3 EJECT	GUILLOTINE	5801	2
DOOR #4 EJECT	GUILLOTINE	5801	2
BOOM 1 DEPLOY	RETRACTABLE PISTON	1MT18SS	1
BOOM 1 EJECT	GUILLOTINE	5800	1
BOOM 2 DEPLOY	RETRACTABLE PISTON	1MT18SS	1
BOOM 2 EJECT	GUILLOTINE	5800	1
BOOM 3 EJECT	GUILLOTINE	5801	2
LP #1 DEPLOY	GUILLOTINE	5800	1
LP #2 DEPLOY	GUILLOTINE	5800	1
LP #3 DEPLOY	GUILLOTINE	5800	1
LP #4 DEPLOY	GUILLOTINE	5800	1
SSD #1 ENABLE	GUILLOTINE	5800	1
SSD #2 ENABLE	GUILLOTINE	5800	1
SSD #3 ENABLE	GUILLOTINE	5800	1

Five categories of pyro functions and flight results are described below:

Door Eject - Four doors in the TP section were ejected using redundant guillotine cutters. Actuation relay monitors and physical separation monitors on each door indicated eject at the pre-programmed times.

PWR Boom Deploy - Booms 1 and 2 in the TP section were released by pyro actuated pin-pullers. Monitors indicate normal operation in accordance with the timeline and full deployment in 3 seconds.

LP Deploy - Four langmuir probes, located in the Beam Diagnostic (BD), section were deployed using the TP section pyro bus. Data indicate that the four actuation relays were switched and deployment occurred at the proper time.

SSD Deploy Enable - Cables were cut in the BD section to enable deployment of the SSD sensors. A motor drive system, actuated from the accelerator controller, successfully completed the deployment.

PWR & HIV Boom Eject - The three TP section booms were ejected, at the times listed in the mechanical timer section of this report, to enable recovery of the payload. An internal door system was included to cover the openings left by the ejected doors and booms. Two of the three doors latched properly; however, the third door was not latched. Analysis of the recovered payload did not clearly indicate the reason for, or the time of, the anomaly. The unlatched door was not detrimental to recovery.

2.3.7 Diagnostic Instrumentation

Diagnostic instrumentation in the TP section included linear accelerometers, magnetometers, a pressure transducer and thermistors. Magnetometer and accelerator flight data confirmed booster, attitude control and recovery events. The ambient pressure transducer became erratic at T+37 seconds and provided no useful data after that time. The transducer can be useful for investigating unusual events during a launch; however, the loss of data was not detrimental to the successful BEAR flight.

In addition to providing temperature data in flight TP section thermistors were useful in monitoring operating temperature limits during extended testing periods. Thermistors were in the following locations:

LOCATION	QUANTITY	NOTES
Transmitters	6	On deck
Converters	3	Inside units
Skin	2	180° apart
Deck	1	Center of deck.

No extreme temperatures were indicated during the BEAR launch. Temperature increases on transmitters and converters were well within normal operating range for those components.

2.3.8 Telemetry

The BEAR telemetry consisted of seven radio frequency data links, an on board magnetic tape recorder and associated signal conditioning, monitoring, formatting and system power circuitry. There was also a radar transponder located in the Booster Control Section (BCS) as well as the Telemetry/Physics Section (TPS) for tracking purposes. The block diagram for the Telemetry/Physics section is shown in Figure 2.3.8. The function and characteristics of these links is as follows:

Link 1 (2269.5 MHz) - 800 kBits/sec PCM signal providing data generated by the physics experiments, the LANL accelerometers, the attitude control system, and the system control and health monitors.

Link 2 (2241.5 MHz) - 63 kBits/sec PCM signals generated by the particle beam accelerator and beam diagnostics system.

Link 3 (2251.5 MHz) - 63 kBits/sec PCM signals generated by the particle beam accelerator and beam diagnostics system. (Same as Link 2 but using a totally redundant path).

Link 4 (2215.5 MHz) - Video camera #1 signals from the beam diagnostic system.

Link 5 (2279.5 MHz) - Wide Band Plasma Receiver Experiment data.

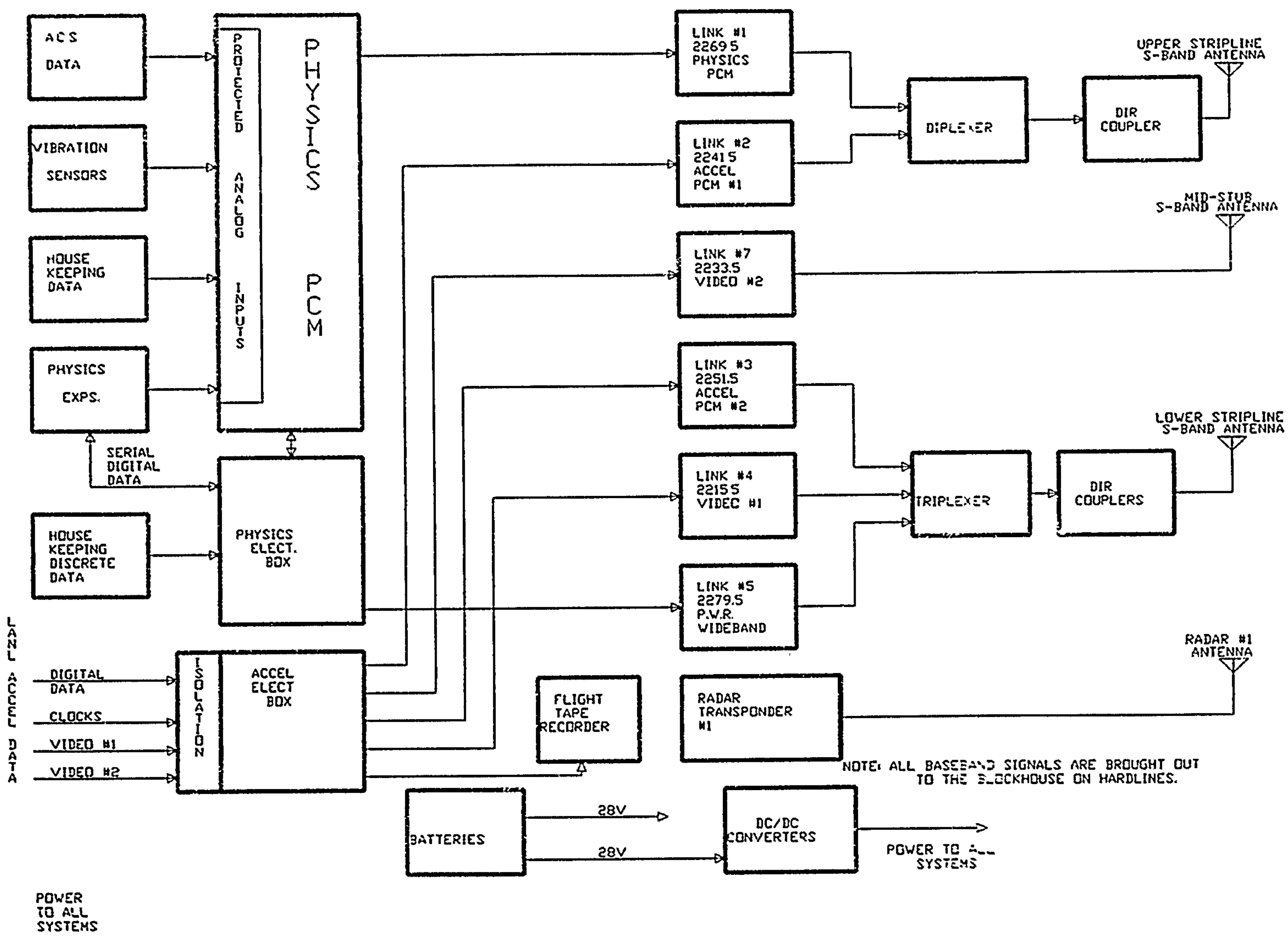


FIG. 2.3.8

BEAR TELEMETRY BLOCK DIAGRAM

Link 6 (2259.5 MHz) - Boost Control System data. This system was totally located in the booster control segment located just above the motor.

Link 7 (2233.5 MHz) - Video camera #2 signals from the beam diagnostic section.

Onboard Flight Tape Recorder - This is covered in Section 2.3.8.1.

The PCM data transmitters were frequency modulated and had an output of 5 Watts, while the video transmitters had an output 10 Watts. Links 1 and 2 drove the upper stripline antenna through a diplexer and links 3, 4, and 5 drove the lower stripline antenna through a triplexer. Link 6 and link 7 drove separate quadraloop antennas without the need of signal combiners. Provisions were made to connect the transmitters to antennas atop the launch building during preflight countdowns due to the shielding effect of the metal sided building. Details of the PCM encoders are covered in Section 2.6.2 of this report.

2.3.8.1 Flight Tape Recorder

As a precaution against a catastrophic failure of the r-f telemetry links, it was determined that a method of onboard recording of the data streams produced by the accelerator and beam diagnostics segments should be included as part of the telemetry system. Initially two recorders were proposed, one for each of the 63 kBit/sec data links. Later this was changed to a single recorder for two reasons: 1) to make room for a second television system link and, 2) descoping had reduced the two PCM links into a single combined data stream which contained both the accelerometer and beam diagnostics information.

The recorder was a modified Digi-Data Corporation model 8320 digital data recorder which was originally designed for streamer tape back up of computer data. The circuitry was modified for the different bit rate, monitors, and remote control of its functions. Figure 2.3.8.1 is a block diagram of the recorder.

The data format was modified to record in a serpentine mode such that all four tracks could be recorded without necessitating a rewind procedure, thus preventing a gap in the flight data. Each of the four tracks had a recording time of 4 minutes thus giving a total recording time of 16 minutes, well in excess of the required time for flight coverage. Line drivers provided the ability to remotely play back recorded data to insure proper operation at any time during preflight activities.

A dc-to-dc converter and filter were added to the unit to allow operation from the payload 28-volt batteries, and the unit was mechanically hardened to survive the shock and vibration of the powered portion of the flight. The only environmental specification that was not met was that the maximum temperature was limited to 45 degrees C due to limitations imposed by the tape cartridge.

It was originally expected that long periods of testing in the vacuum of a test chamber would be encountered. To

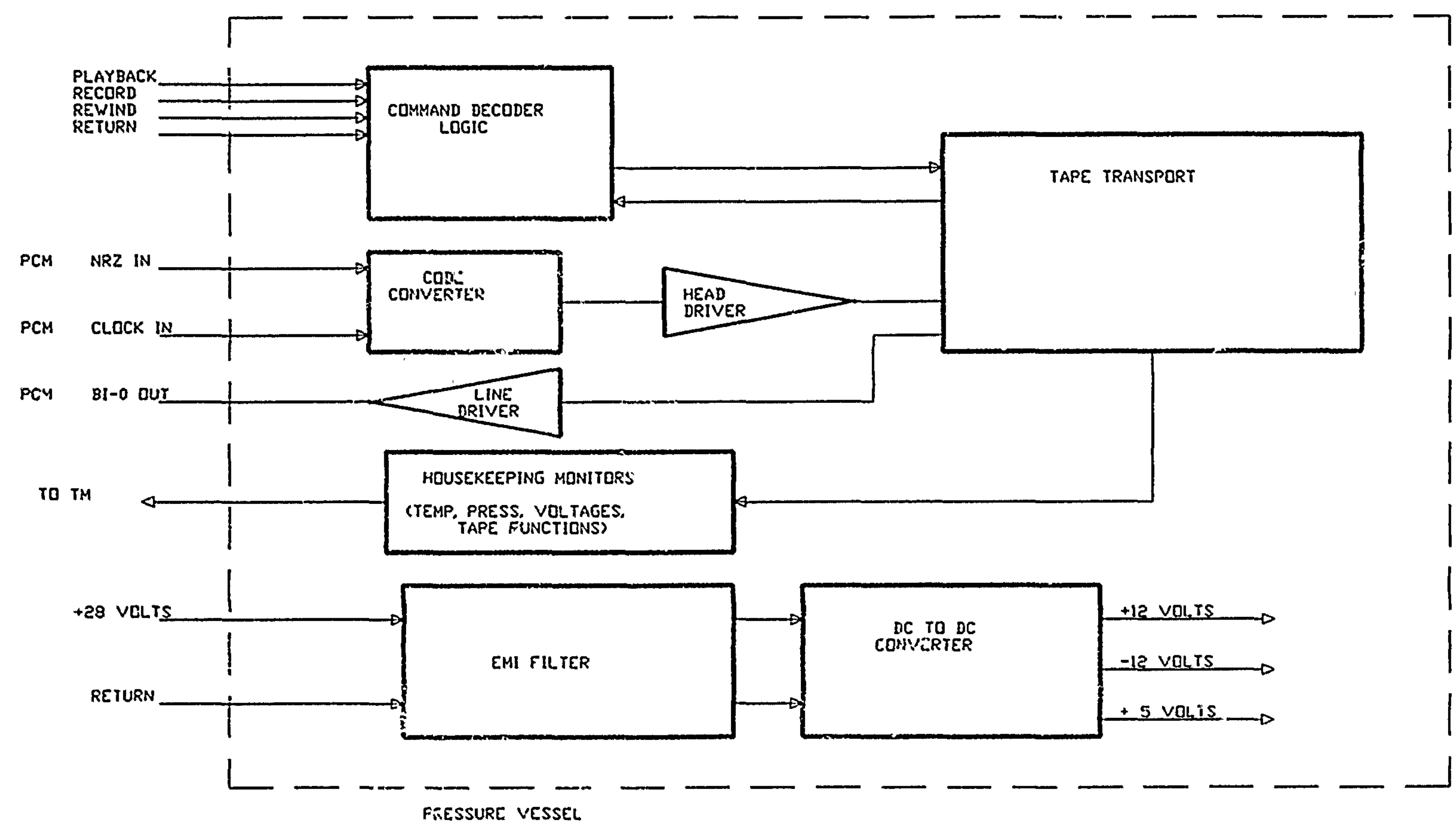


FIG. 2.3.8.1

FLIGHT TAPE RECORDER

prevent outgassing and loss of lubricants, a pressure vessel was designed to contain the recorder.

No difficulties were encountered during the many system level tests that were made at LANL and WSMR. The recorder was recovered after the flight and returned to NU for post flight evaluation. Analysis of telemetered data showed that all functions took place at the preprogrammed intervals and that the LANL data was properly recorded throughout the flight.

2.3.8.2 Electromagnetic Interference Testing (EMI)

Precautions are routinely taken in the design and construction of the circuitry required to actuate the various pyrotechnic devices used in sounding rocket programs. These devices are used for the deployment of doors, probes, and nose cones, as well as for stage separations and recovery functions. These events are obviously mission critical, and as such, incorporate redundant batteries, ignition squibs, and initiation circuits.

Due to the unusually severe electromagnetic fields capable of being produced by the high energy neutral particle beam experiment, a series of tests were proposed to carefully monitor the interference levels encountered under both normal operation and during arc over of the ion generator.

The circuitry designed for this test is shown in Figure 2.3.8.2 and consists of a shielded housing and cables, sets of instrumentation amplifiers and line drivers, and an isolated dc-to-dc converter for power. The inputs were connected differentially directly across each firing squib of the

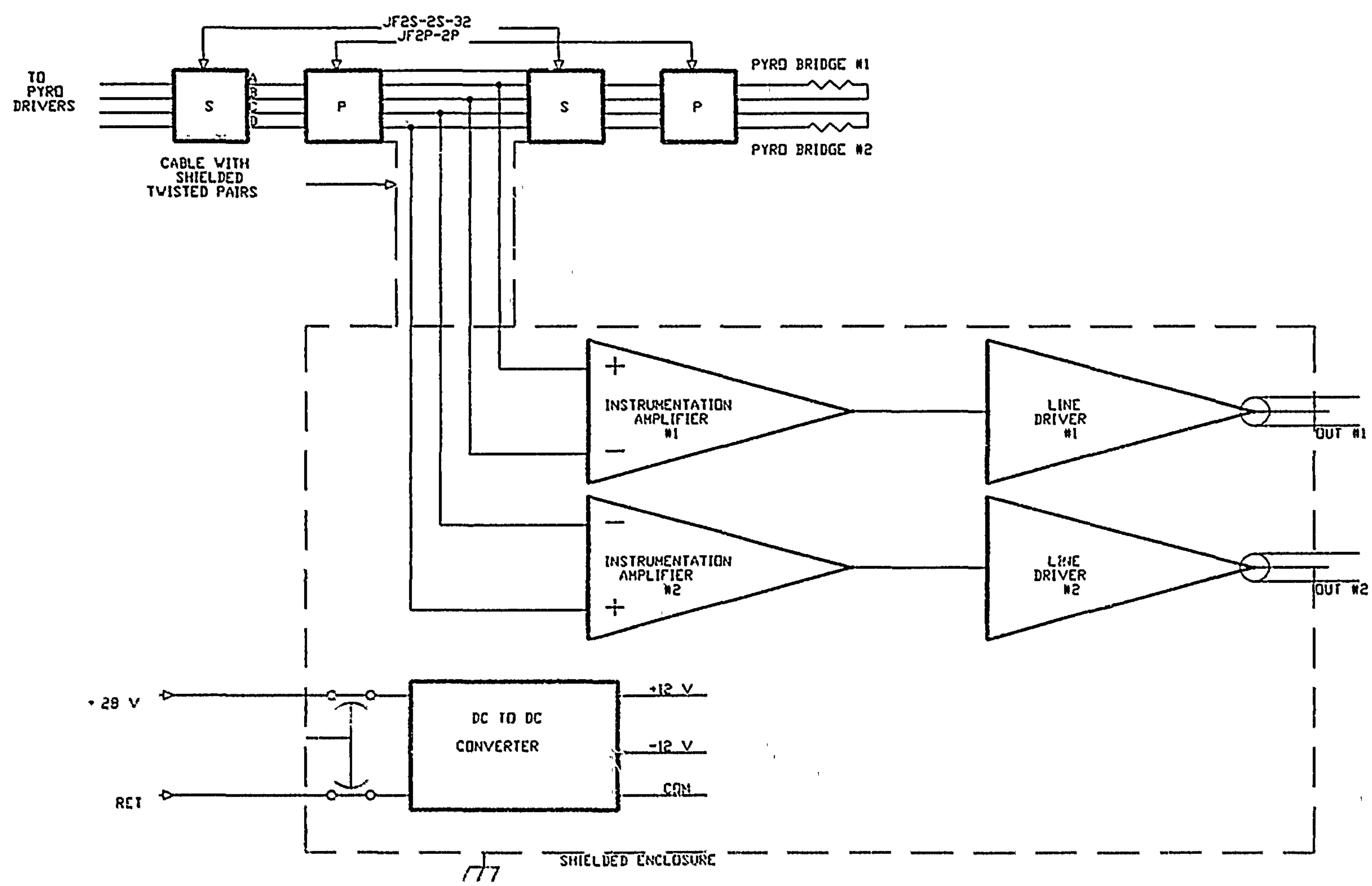


FIG. 2.3.8.2

EMI TEST AMPLIFIERS

pyrotechnic devices by the insertion of a double ended matching connector. This was done to cause the least disturbance to the normal position of the cabling.

The outputs of the EMI monitor circuits were recorded on strip charts for low-frequency analysis and digitizing ocsilloscopes for the high frequencies. The digitizing oscilloscope had provisions for producing hardcopies of its measurements. The tests were conducted at LANL in March of 1989 and each device was tested under normal flight conditions and during an arc over event. At no time during the tests did interference exceed 25 millivolts. The data taken during these tests was given to the mission director for more detailed analysis and accepted as valid proof as to the effectiveness of the shielding.

2.3.8.3 <u>Booster Control System</u>

The telemetry portion of the Booster Control System consisted of a 64 kBit/sec PCM encoder, dc-to-dc converter, S-Band transmitter, C-Band transponder, antennas and housekeeping sensors. The main purpose of this telemetry system was to support the preflight and flight monitoring of the inertial platform, batteries, gyroscopes and actuators which control the booster's trajectory. A line driver was provided to monitor the PCM signal directly.

Nominal data values were monitored throughout the flight with no loss in telemetry or tracking signals at any time until re-entry. As the motor was separated from the payload for experimental purposes, there were no provisions to recover any portion of this system. Figure 2.3.8.3 is a block diagram of this system.

2.3.8.4 Physics Plasma-Wave-Receiver Link

This experiment was designed by the Naval Research Laboratory for the direct measurement of high frequency plasma responses to the neutral particle beam. Due to its requirement for a bandwidth of approximately 500 kHz, a dedicated r-f link was assigned to this instrument. This approach resulted in an unusual (for telemetry) direct fm modulation of the transmitter (Link #5) by the analog output of the instrument. One of the difficulties encountered by this scheme was that the instrument had no output until the data taking portion of the flight and thus proper modulation could not be preflight tested. At the suggestion of NU, a GSE controlled signal at maximum expected level and frequency was incorporated into the instrument for verifying proper operation of the instrument and its transmission link as well as setting the proper deviation. The output of the plasma-wave receiver was conditioned with a linear wideband preamplifier for driving the transmitter and a wideband line driver for hard line monitoring.

2.3.8.5 Video Systems

Two video cameras were utilized for diagnostic purposes in the beam diagnostic section of the payload. The first camera monitored the beam as it exited the neutralizer and the

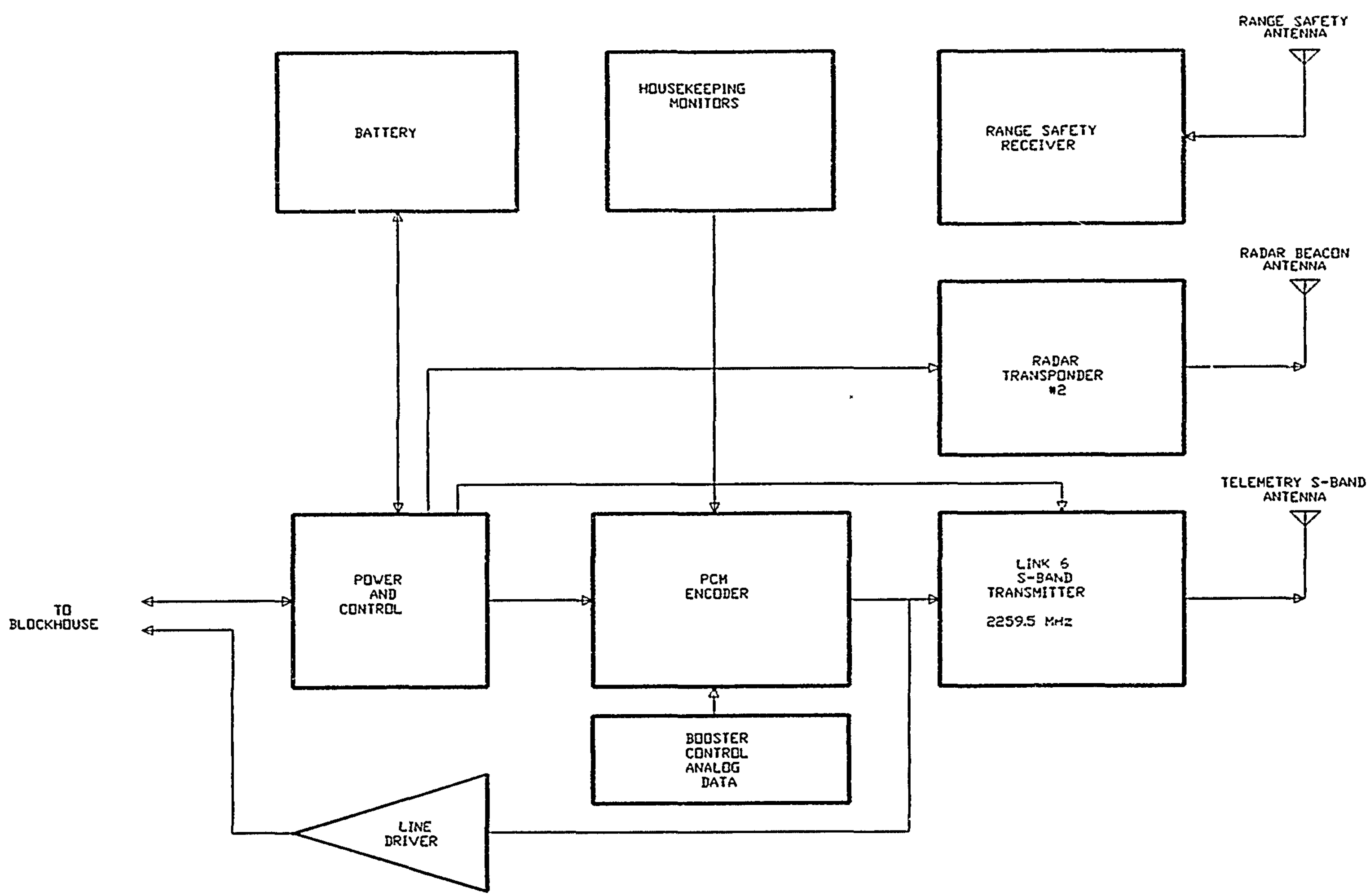


FIG. 2.3.8.3

BOOSTER CONTROL SYSTEM

second monitored the beam along its exit path as it left the payload. The cameras were specially gated and image intensified to provide low-light sensitivity and resolution. These cameras were designed by EG&G and met the RS-170 standard for video signals.

Early in the program the two cameras were to time share a single video link, with the time of switching to be coordinated under control of the beam diagnostic section controller. It was later determined by LANL that it would be necessary to have full time video coverage of both functions. This necessitated major changes in the telemetry section. The backup flight tape recorder was eliminated to make room for the new video transmitter, isolation transformer and batteries. New stub antennas were acquired and attached to the skin of the telemetry/physics section. Also, extra video and line driving amplifiers were added to the electronics support box to provide the required support.

The hard lines from the launcher to the blockhouse and control utilized optical fiber links for the video signals as well as the PCM bit streams. The fiber optic links were installed on the range in anticipation of this vehicle. Once these links were properly connected, they provided the long distance support for high-bandwidth systems which had been previously unavailable. During the flight, both cameras gave indications of the beam being formed and transmitted properly.

2.4 Boosted ARIES (HPB)

2.4.1 Background

The Boosted Aries program, also known as the High Performance Booster (HPB), was introduced to test the operational parameters of a previously untested combination of launch vehicles for sub-orbital scientific payloads. The vehicle consists of a US Navy Talos MK 11 Mod 2 booster and a Minuteman I M56A1 (Aries) second stage sustainer. This combination was designed to be compatible with the 20K launcher located at Wallops Flight Test Center.

2.4.2 Overview

Figure 2.4.2.1 is a drawing of the vehicle on its launcher in a horizontal position and Figure 2.4.2.2 is a plot of the calculated payload-weight performance. The Talos is a fin stabilized motor whose fins were enlarged for this project due to the 54 inch diameter aft skirt of the M56A1 motor which would prevent proper aerodynamic down wash over normal size fins. Control of the M56A1 sustainer was accomplished via a MIDAS platform and rate gyroscope which actuated the four gimbaled nozzles of the motor as preprogrammed in the flight controller.

While the main purpose of this flight was to test this launch configuration, there were also "piggybacked" experiments onboard. These included a passive masker radar experiment from MIT/Lincoln Laboratories and the test of an

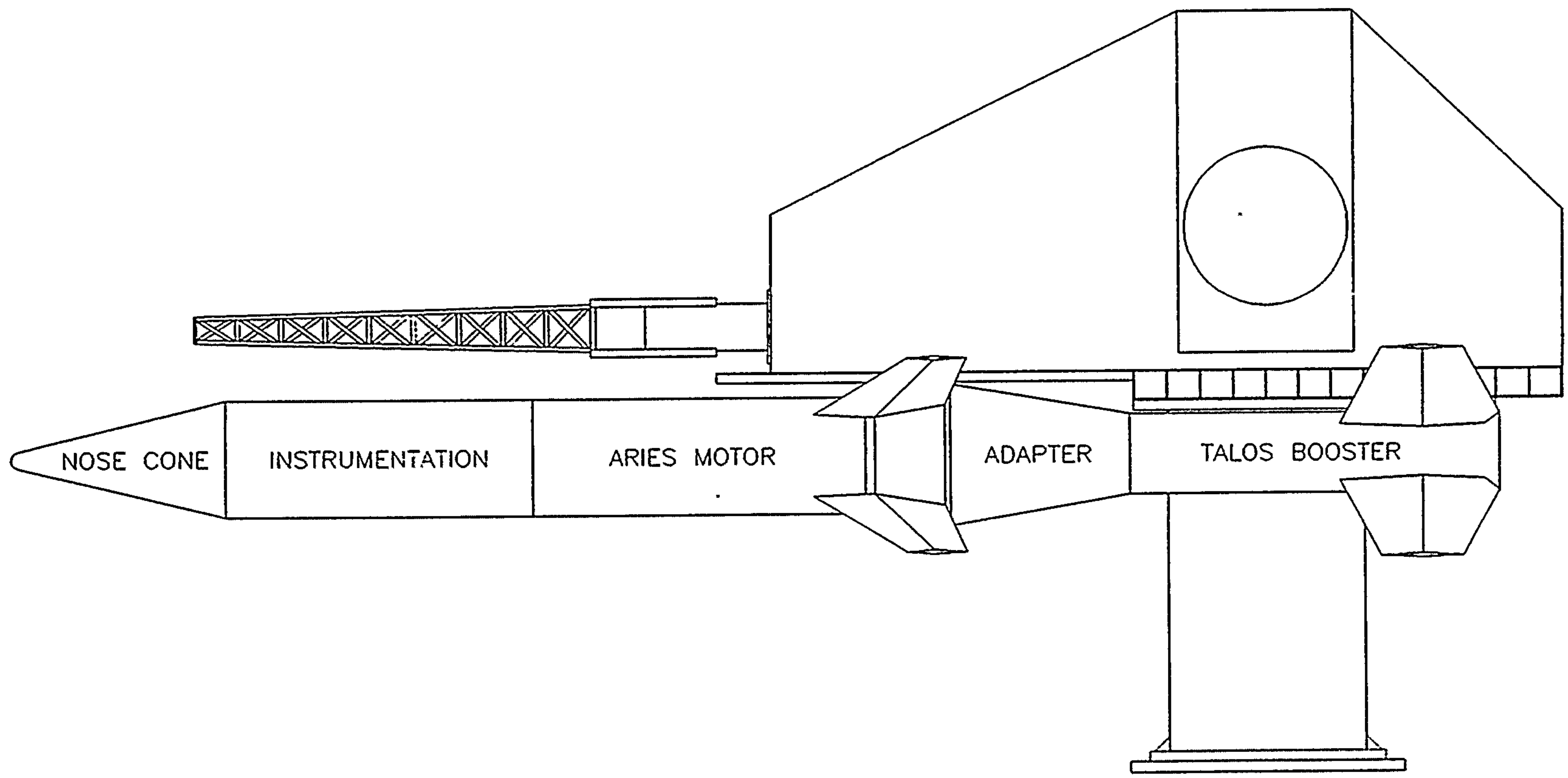


FIG. 2.4.2.1

BOOSTED ARIES

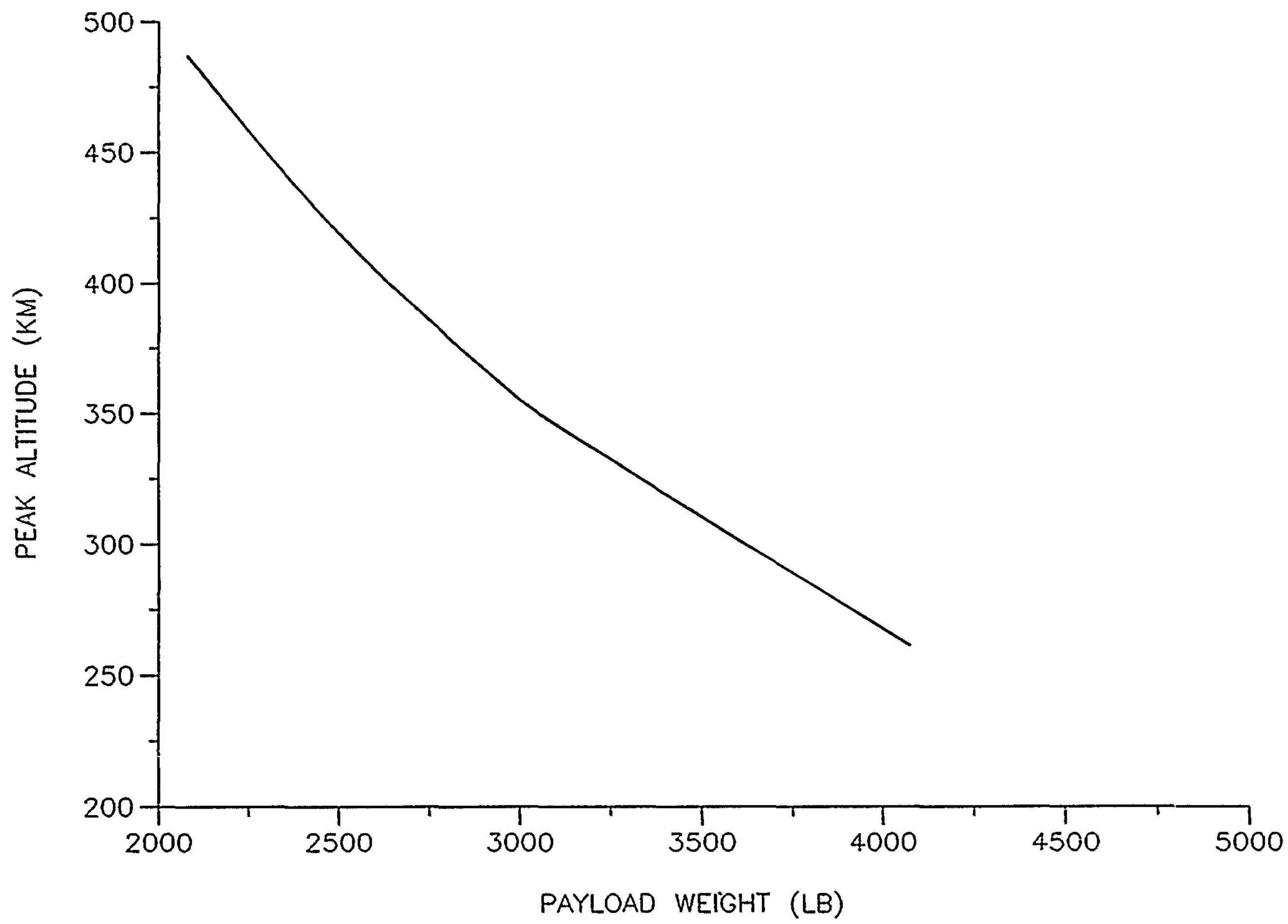

500
450
400
350
300
250
200
PEAK ALTITUDE (KM)
2000
2500
3000
3500
4000
4500
5000
PAYLOAD WEIGHT (LB)

FIG. 2.4.2.2

inertial guidance system built by Litton Industries. Power for all internal and external functions was supplied by the vehicle integrator, Space Data Corporation.

2.4.3 Telemetry

Onboard telemetry consisted of a television camera and its associated r-f transmission system, as well as a PCM data acquisition system for transmission of flight engineering, housekeeping, ad the experimental signals. A C-band radar transponder was used for flight trajectory verification. As part of the flight engineering instrumentation, four accelerometers were installed to measure the shock and vibration levels to which this launch configuration subjected the payload. Figure 2.4.3 is a block diagram of the flight telemetry and its associated inputs and Table 2.4.3 is a general listing of various program specifications.

The inputs to the PCM encoder were as follows:

1. Boost Control System - 48 KBits/s Digital/Parallel plus housekeeping analogs.

2. Inertial Navigation System - 51 KBits/s Digital/Serial.

3. Four Accelerometers - sampled at 8000 samples/s and 1000 samples/s.

4. Masker Radar Experiment Housekeeping

5. Telemetry Housekeeping

The vibration sensors were Endevco Model 2228C triaxial accelerometers having a flat response from 20 to 10,000 Hz followed by Endevco Model 2680M12 matched charge amplifiers

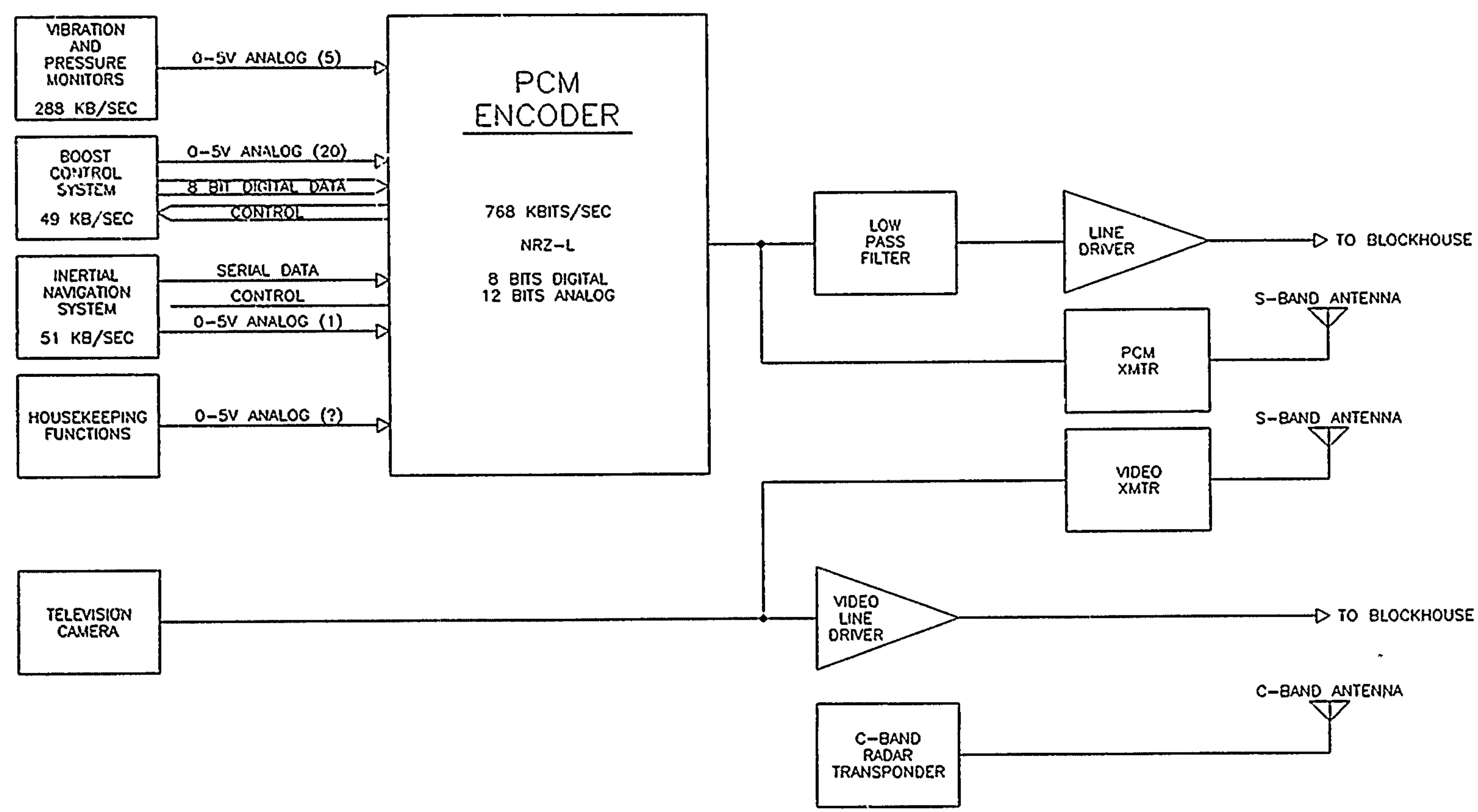


FIG. 2.4.3

BOOSTED ARIES

TABLE 2.4.3

HPB-BOOSTER ARIES

VEHICLE CONFIGURATION
- WEIGHT: 2583 LBS.
- DIAMETER: 44.28 INCHES
- LENGTH: 552.4 INCHES

SCIENTIFIC EXPERIMENTS --- (SUPPLIERS)
- PASSIVE MASKER RADAR EXPERIMENT - MIT/LL
- INERTIAL GUIDANCE TEST UNIT - LITTON
- THREE AXES VIBRATION TRANSDUCERS - NU

SUPPORT SYSTEMS --- (SUPPLIERS)
- ARIES GUIDANCE - SPACE DATA

RF SYSTEMS
- PCM/FM/FM TELEMETRY LINK:
  - 2279.5 MHZ 10 WATTS 768 KB/S PCM
- VIDEO TELEMETRY LINK:
  - 2215.5 MHZ 10 WATTS RS17 TV
- BEACON TRANSPONDER:
  - REC - 5690 MHZ XMT - 5765 MHZ DOUBLE PULSE - 5uSEC SPACING
- RECEIVERS (2):
  - 412 MHZ - COMMAND CONTROL/DESTRUCT

PAYLOAD TIMING
- ELECTRONIC/MECHANICAL FLIGHT CONTROLLERS - SPACE DATA

MECHANISMS
- TV DOOR EJECT - SPACE DATA

BOOST VEHICLES
- BOOSTER - TALOS MK 11 MOD 2
- SUSTAINER - MINUTEMAN I (ARIES) M56A1

adjusted to produce full scale readings of +/- 10 G and +/- 100 G from their two outputs. A single axis model 2220C with similar characteristics was also used on the flight axis, remote from the triaxial unit, to measure any structurally induced variations. The +/- 10 G outputs were sampled at 8000 samples/sec and the +/- 100 G outputs were sampled at 1000 samples/sec.

Attempts to launch this payload were made at Wallops Island Flight Facility in October 1989, December 1989, and January 1990. The early attempts were aborted due to difficulties in the attitude control system, the range safety control system and weather.

2.4.4 Conclusion

The vehicle was launched on January 30, 1990 from pad 3B at 1622 EST, reached an altitude of 423 km and impacted 185 km down range. Official post flight performance evaluations were given as follows:

Prime Experiment	100%
Secondary Experiment	100%
Telemetry	100%
ACS/Inertial Platform	100%
Transponders	100%

The television signals received from the payload were exceptionally clean and devoid of r-f dropouts.

2.5 LIFE (LEAP Integrated Flight Experiment)

2.5.1 Background

The LIFE I payload was designed to provide a support and test platform for the GTP (Ground Test Projectile) developed under the LEAP (Lightweight Exo-Atmospheric Projectile) program. A Black Brant rocket launched from the WSMR was selected to carry the payload to an altitude of 175 miles. After several attitude changes by the whole payload to obtain reference data, the GTP will be ejected from the payload on the down leg of a trajectory to perform a number of pre-programmed maneuvers in the vicinity of the payload while outside the earth's atmosphere. Visual observation of the GTP will be maintained through a television link in the payload, while the internal performance and the flight data gathered by the GTP will be monitored through a low power TLM transmitter on board the projectile. In addition to the possible direct reception by the ground stations, that signal also will be received in the payload and relayed to the ground stations.

2.5.2 Overview

The LIFE I 17-inch diameter payload configuration is presented in Figure 2.5.2 while the specifications are summarized in Table 2.5.2. The Electronics Research Laboratory was primarily concerned with the Ogive and the three sections that follow: Front Payload Module (FPM), Aft Payload Module (APM), and the Support Module (SM). These modules provide a direct support for the GTP.

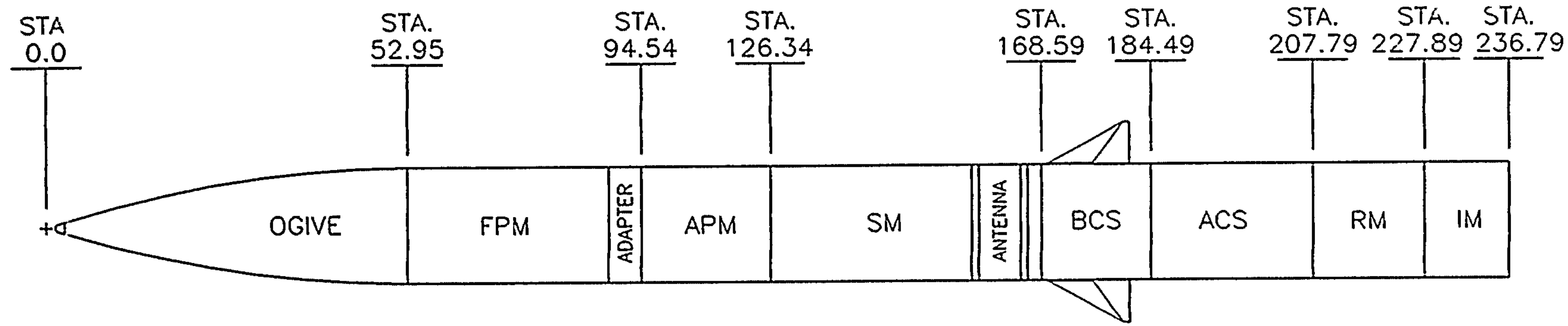


FIG. 2.5.2

LIFE CONFIGURATION

TABLE 2.5.2

LIFE PAYLOAD DATA

PAYLOAD CONFIGURATION

- WEIGHT: 902 LBS. (ESTIMATED)
- DIAMETER: 17.26 INCHES
- LENGTH: 236.8 INCHES

SCIENTIFIC EXPERIMENTS --- (SUPPLIERS)

- GROUND TEST PROJECTILE - (BOEING)

SUPPORT SYSTEMS --- (SUPPLIERS)

- TV CAMERA & CONTROL MODULE - (NU)
- IR SOURCE & HEATER CONTROL MODULE - (NU)
- 2 ACCELEROMETERS - (NU)
- 3 AXIS MAGNETOMETER - (NU)
- PRESSURE TRANSDUCER - (NU)
- DIGITAL MULTIPLEXER - (NU)
- ENCODER - (NU)
- DUAL REGULATOR MODULE, 5V - (NU)
- 4 THERMISTORS - (NU)

RF SYSTEMS

- RANGE SAFETY RECEIVER 409 MHZ
- L-BAND RECEIVER 1440.5 MHZ
- COMMAND RECEIVER 550 MHZ

PCM TELEMETRY LINKS:

2251.5 MHZ	2 WATTS	SUPPORT
2279.5 MHZ	2 WATTS	GTP

VIDEO TELEMETRY LINK:

2215.5 MHZ, 10 WATTS,

BEACON TRANSPONDER:

C-BAND, DOUBLE PULSED

PAYLOAD TIMING

- NU APCAM, REDUNDANT CONTROLLERS, 7 CONTROL RELAY MODULES

MECHANISMS

- SEPARATION - OGIVE

The projectile in its container, its support electronics known as the Payload Interface Module (PIM) and some of the plumbing to carry a coolant to the focal plane and the electronics of the GTP reside in the FPM. A receiving antenna for the GTP TLM signal, an IR source and a video camera also share the space of the module.

The APM holds the bottles of the compressed gas used as the coolant. The plumbing to charge these high pressure vessels and the conditioning devices for the gas before it passes into the FPM are also contained in this section. Responsibility to instrument these two sections was shared between Boeing, AFGL and ERL.

The Electronics Research Laboratory had a nearly exclusive responsibility to instrument the SM module in LIFE I. The module contains the following microwave links: GTP signal transceiver, TV and payload monitor data transmitters, command receiver, RADAR transceiver and the range safety receiver to enable the GTP launch process. Also located in this section are the payload controller/timer and PCM encoder along with the necessary interfaces to other payload modules supporting the flight and the recovery. Payload batteries, power distribution and pyro circuits also are housed in here. Interfaces for commands and monitor data from the Boost Control System (BCS), Attitude Control System (ACS), Recovery Module (RM) and the Ignition Module (IM) are provided in this section.

2.5.3 Configuration

In the original LIFE payload design, all GTP hardware and the related cooling system were packaged in a single 17-inch diameter section. An avionics unit (GTPAU) was also included and later deleted from the program. Subsequently, the supplier of the payload skins (Bristol Aerospace) defined a maximum length of 50-inches for their manufacturing process. This constraint, and changes presented by Boeing at the October 1989 PCR significantly impacted the preliminary FPM and SM design. Conceptual changes in the GTP cooling system, requirements for a larger high pressure storage tank, and the addition of a 500 watt gas line heater dictated a totally new mechanical design of the FPM. Also, the additional power requirements impacted packaging of the SM.

The entire GTP payload system evolved into a segment totaling 73.39 inches in length and designated as the FPM/APM. The segment consists of a single rack structure with a bulkhead supporting the GTP assembly forward and the revised cooling system aft. This configuration allows access to cooling system and electrical interfaces at the bulkhead. After all components are installed in the rack, skin sections will be installed from both the forward and aft ends. Figure 2.5.3.1 depicts the section aft of the bulkhead with the two cylindrical storage tanks, umbilicals, the gas line heater and associated valves and plumbing. Batteries and controls for the heater supply are packaged on the bottom deck of this

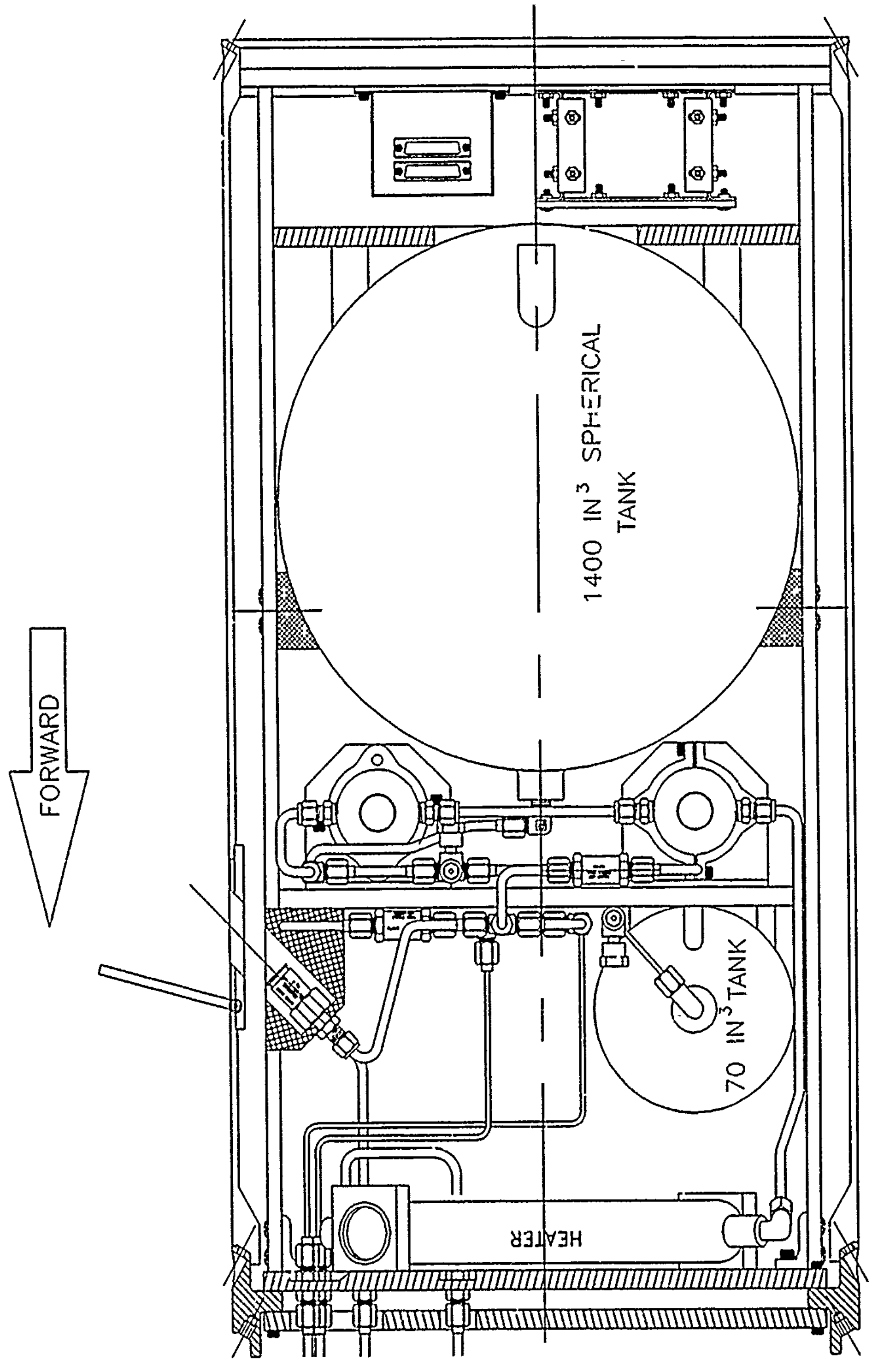


FIG. 2.5.3.1

LIFE AFT PAYLOAD MODULE

section to preclude the need for interface connectors to the SM for this high current application.

Fabrication drawings for the FPM and APM skin segments were provided to Bristol Aerospace for manufacturing in March 1990. A standard ejectable ogive was also ordered at that time. Coordination was required between ERL and Bristol engineers regarding the manacle band separation mechanism, integration of the push-rod system and assembly of the spring loaded forward eject system. Space was allocated in the top deck of the FPM to accommodate the push-rod and ERL developed the mechanical interface to the eject mechanism. Wiring to the ogive consisted of a separation monitor, thermistors and an aliveness indicator for the television camera.

Since the SM section was not required for the preliminary testing at Boeing, its design lagged the FPM/APM and it was not included in the Bristol order. Rather, a forging was ordered and all SM skin machining was accomplished on a single sub-contract. This was an efficient alternative since the SM required extensive machining, in addition to the standard tension joints. Two access doors, three umbilical brackets and seven external antennas had to be accommodated. A cut-away assembly drawing of the LIFE SM is presented as Figure 2.5.3.2. As indicated, antennas are rotated and a longeron is removed for clarity. The internal rack structure, used to mount the components and to attach the wiring harness, illustrates typical sounding racket payload packaging.

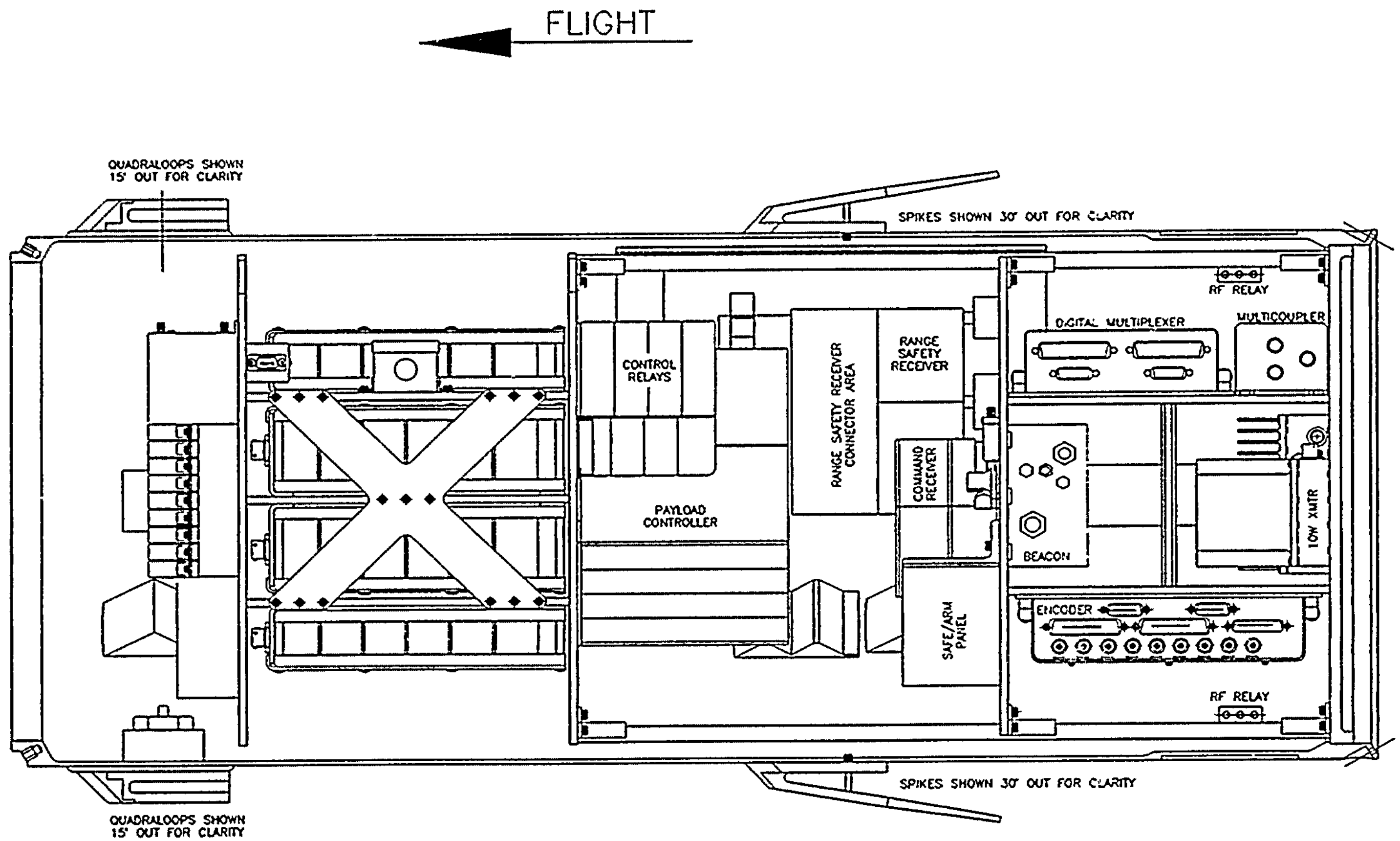


FIG. 2.5.3.2

LIFE SUPPORT MODULE

2.5.4 Power Systems

Nicad batteries, described in Section 2.6.1, were packaged in the SM along with related dc/dc converters and switching relays operated by the controller. A new design, incorporating programmable power supplies in the ground support consoles, was incorporated for the LIFE payload. These supplies provide both external power to the payload and battery charging, precluding the need for two independent consoles. Details of the ground power distribution system and options for computer interfacing are presented in Section 2.7. The following are the payload battery allocations and nominal operating currents:

ID	VOLTS	AH	TYPE	ASSIGNMENT	AMPS
BATT 1	28.8	4.0	NICAD	SUPPORT DIAGNOSTICS	.5
				BEACON TRANSPONDER	1.0
				L BAND RECEIVER	.65
				COMMAND RECEIVER	.8
				CONTROLLER 1	.3
				BIT SYNC	.1
BATT 2	28.8	4.0	NICAD	TV TRANSMITTER	4.0
BATT 3	28.8	4.0	NICAD	PCM TRANSMITTER (GTP)	1.0
				PCM TRANSMITTER(SUPPORT	1.0
				ENCODER/DIGITAL MULTI-PLEXER	.15
				TV CAMERA (.33A @ 12V)	.17
				TV ZOOM LENS (.05A @ 12V)	.025
				TV ALIVENESS (.03A @ 12V)	.015
				CONTROLLER 2	.2
BATT 4*	28.8	1.2	NICAD	RANGE SAFETY RECEIVER	.8
BATT 5	28.8	2.2	NICAD	GTP	2.1
BATT 6	28.8	2.2	NICAD	SOLENOID	2.76 MAX
BATT 7	28.8	4.0	NICAD	PAYLOAD INTERFACE MODULE	6.4 MAX
BATT 8	9.6	1.2	NICAD	PYRO POWER 1	
BATT 9	9.6	1.2	NICAD	PYRO POWER 2	
BATT 10	28.8	5.0	SILVERCEL	GAS LINE HEATER	17.36
				IR SOURCE	6.0

Battery #4 is unique and was supplied by WSMR as part of the range safety receiver system. The cylindrical housing is packaged in the SM and an access panel is provided for both the range receiver and the battery.

Power required by the gas line heater (500 watts) and the IR source (200 watts) dictated a battery capable of high rate discharge. HR5 silvercells were selected for the application and a housing for 19-cells (1.5 volts nominal per cell) was developed. Unlike nicads, these cells are activated with a liquid electrolyte, have a limited shelf life, require special handling and must be monitored closely during charging. The silvercell battery pack is located on the bottom deck of the APM section and is installed through an access panel on the skin. A dedicated power relay module is mounted adjacent to the battery pack and includes an electrical interface connector for the silvercells. This configuration minimizes the length of high current wiring required and the number of interconnections, since only relay control and function monitors need traverse to the SM interface.

Redundant pyro circuits, consisting of 9.6 volt nicad batteries, safe/arm relays and safe/arm connectors are included in the SM. In addition to releasing the ogive, the pyro voltages will be provided to the FPM payload interface module and used for GTP release related events.

2.5.5 Microwave System

Four telemetry links are instrumented in the LIFE I payload. One of the links receives the data transmitted by the GTP. After restoration and conditioning the data is re-transmitted on another link to ground. Two more links are used to transmit the video signal of the TV camera observing the GTP and the monitor data gathered from all sections and instruments of the payload. A block diagram of the microwave system is presented in Figure 2.5.5.

2.5.5.1 GTP Data Link

The GTP broadcasts its one Mbit/s Bi-Phase data stream at 1440.5 MHz over a phase modulated (PM) transmitter with a nominal power of 200 mW. A radiating stub antenna is attached to the back end of the projectile. In the design of the receiving subsystem it was anticipated that the radiation pattern of the GTP will exhibit some deep nulls. (Measurements of the radiation pattern by Boeing indeed confirmed that a very deep null exists about 20 degrees of the longitudinal axis looking into the focal plane assembly.) Since the low power of the GTP transmitter precludes a direct high quality data reception at the ground stations, the payload transceiver is the primary data link for the GTP data. Therefore, every effort was made to insure a high carrier signal to noise ratio in the receiver design.

Fig. 2.5.5.1 shows the block diagram of the subsystem. The receiving antenna - a Helix with a 9 dBi nominal gain is followed by a directional coupler employed to receive the signal while the GTP rests inside its container within the payload. A band pass filter prevents the strong S-band signals radiated by the payload TLM antennas from saturating the pre-amplifier. The pre-amplifier is employed to insure a low noise figure (3 dB) for the receiver. The projected

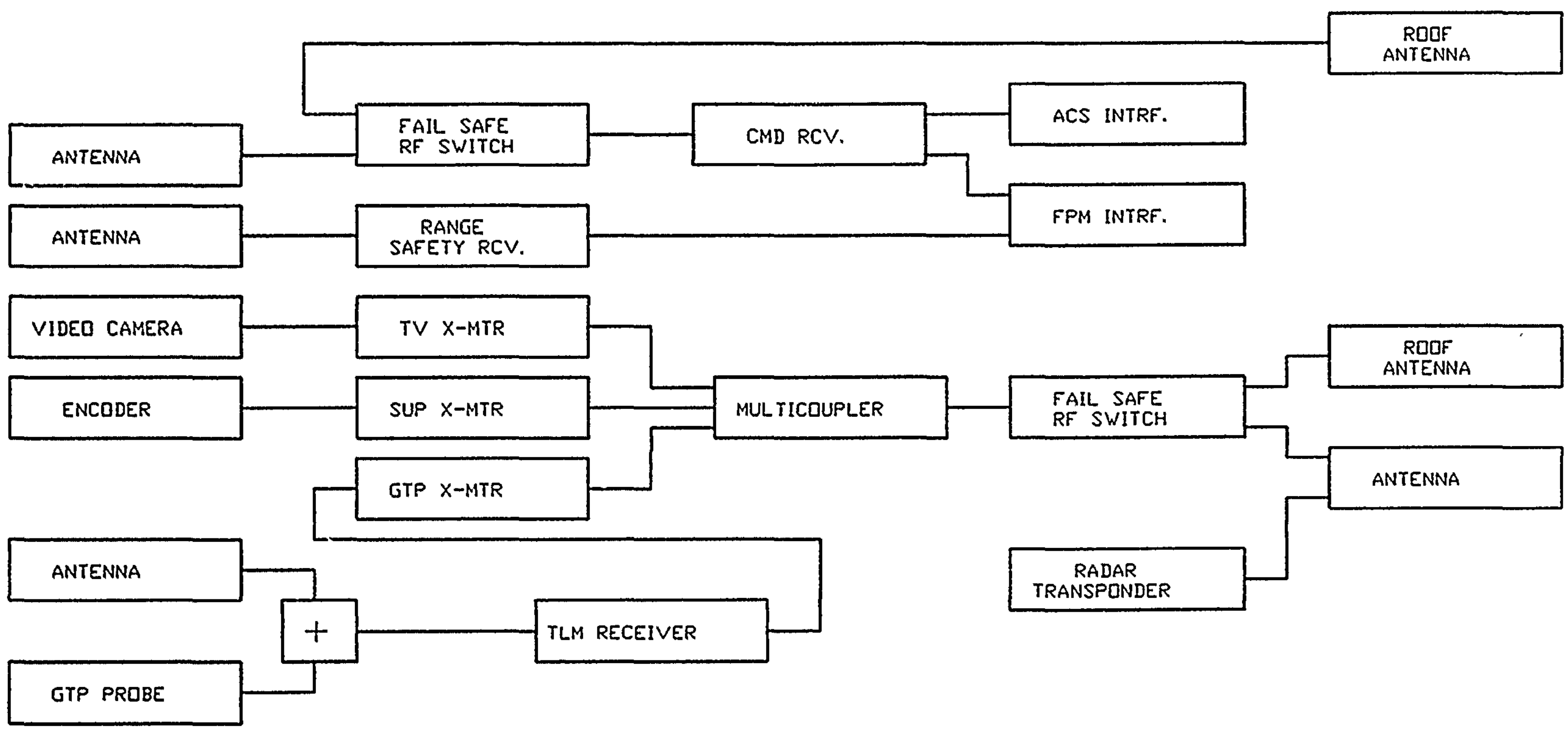


FIG. 2.5.5

LIFE 1 MICROWAVE SYSTEM

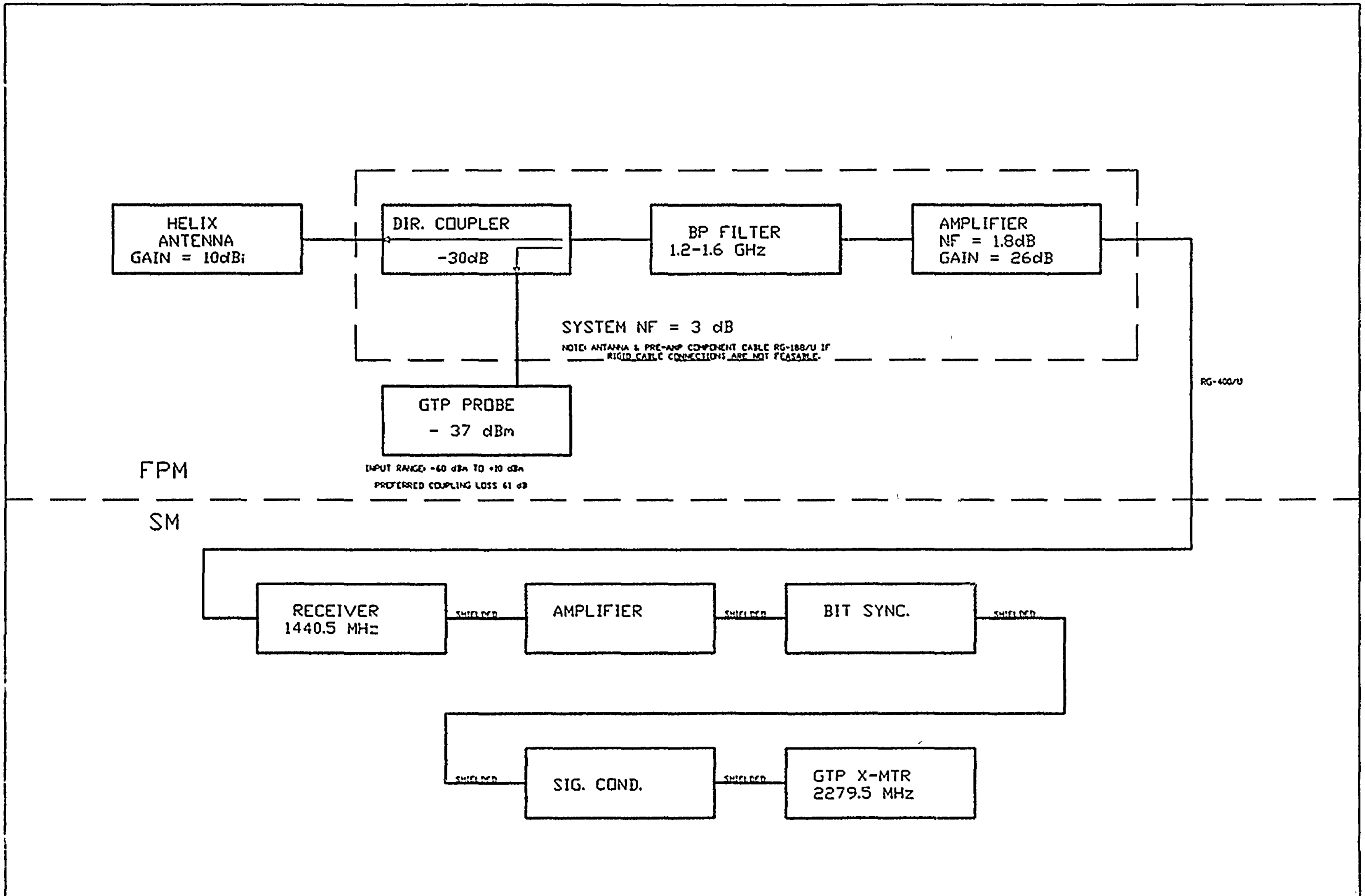


FIG. 2.5.5.1

GTP SIGNAL TRANSCEIVER

carrier signal-to-noise ratio of 29 dB provides for a 13 dB noise margin above the level necessary to maintain the Bit Error Rate (BER) of less than one in a million. This projection is based on a rather conservative assumption that the GTP is at a distance of 800 meters and operates with an antenna gain of -15 dBi. The possibility that a deep antenna null is encountered and the S/N deteriorates can not be discounted. Therefore, a bit synchronizer following the receiver is included. Its task is to prevent noise accumulation in the transceiver link by recovering and restoring the GTP PCM signal before re-transmitting it to ground. A two watt S-band transmitter completes the data link to ground with a 29 dB worst case S/N.

2.5.5.2 TLM Links

In addition to the GTP data transmission link to ground two other S-Band TLM links are included in the LIFE I payload. One of the links carries the video information from the camera. The second link is used to transmit the payload housekeeping information.

A 10 W wide-band transmitter with CCIR-405 pre-emphasis broadcasts the signal from an on-board TV camera. The signal bandwidth, limited to 3.5 MHz by a filter, deviates the transmitter to fill a 10 MHz IF bandwidth when observing a simulated GTP image on a dark background. The minimum expected carrier signal-to-noise ratio at Jig-67 ground receiving site of WSMR is above 34 dB during the entire GTP flight. This S/N is adequate to produce sufficiently clear monitor images for the "joy stick" operator controlling the payload attitude as well as for the visual GTP flight evaluation.

All payload and flight control equipment function monitor signals are converted into a PCM bit stream and transmitted over a 2 W S-band link. The three microwave signals: GTP, TV and monitor PCM are combined in a tricoupler for transmission through a single wrap-around stripline antenna.

The PCM data transmitter was not included in the original design. The low frequency data (20 kbps) in the NRZ-S format was combined with the 1 Mbps bi-phase GTP signal for transmission over the GTP data link. Since for all practical purposes the power spectrum overlap of the two signals is insignificant, 3-pole low-pass and hi-pass filters may be used to separate the two signals after demodulation. (At reasonably good S/N only the low-pass would suffice if a proper pre-emphasis for the combination is used.) The filters for all receiving sites were to be provided by ERL. Unfortunately some objections were raised against this "unorthodox multiplexing scheme" (which has been successfully flown on other occasions) because some of the signals carry vehicle performance information used by the range safety. As a result, an independent link was added for the housekeeping data and the data stream was converted to Bi-Phase PCM.

2.5.6 Commands and Signal Switching

A command receiver/tone decoder distributes commands received from the ground at 550 MHz through its own antenna array. Eleven channels are available. Most of the available commands are employed to control the ACS in the payload during the flight of the GTP. The ground based operator may intervene any time the ACS fails to keep the payload, and thus the TV camera, pointed at the free flying GTP. Zoom control commands for the lens of the TV camera are also available. Finally a command can be issued to disable the release of the GTP if a malfunction in the projectile is detected through its telemetry data.

The release of the GTP is enabled from the ground by Range Safety. A Range Safety Receiver operating at 409 MHz issues the command. A separate antenna array is used for the receiver. Also, a C-band RADAR Beacon is included in the payload. Its antenna is incorporated into the TLM stripline antenna.

Fail-safe microwave switches are included in the telemetry and the command links. Past experience has shown that the time for system tests requiring radiated power always exceeds the allocated time in the planning of the mission. This produces complications on the Range where electromagnetic radiation is not only strictly controlled, but also rationed. When permission to radiate is granted while the vehicle is on the pad, the metal enclosure of the launcher must be removed to expose the payload antennas. Crews must be rounded up to perform this task. This removal of the housing will be particularly acute in the LIFE program where the ambient temperature of the payload must be well regulated.

During routine testing, these problems normally would be solved by disconnecting the transmitters from the payload antennas and connecting them to the cables leading to some roof antennas, the blockhouse or just loads, as the occasion requires. This antenna swapping is often performed "blind" and in awkward positions - conditions inviting breakage and errors. The fail-safe switches when activated from the blockhouse, complete circuits to connectors mounted on the skin of the payload. The dependence on the Range is decreased, while the flexibility in testing is greatly enhanced without the difficult access to the interior of the payload.

Since this component was recognized as a candidate for a possible single-point failure, selected switches were tested to qualification levels of AFGL BBX Test Specificatioms without any externally noticeable break in signal flow. The flight switches were tested to acceptance levels of the same specification. The projected savings in time, convenience and reliability more than compensates for the small added cost.

2.5.7 Control System

Redundant APCAM electronic controllers, described in Section 2.6.3, were utilized for all payload switching functions except for the up-link commands defined in the previous section. Operation of the 64-function controllers was similar to the BEAR program where controller #1 operated all pre-launch and in-flight functions and controller #2 provided redundancy. In addition to the flight timeline, a series of unique test sequences were developed for the LIFE program. A total of seven-control relay modules are packaged in the SM to interface the controller commands to the individual functions.

After the design was complete, laboratory prototype tests at Boeing indicated switching transient problems with GTP power and power to the payload interface module (PIM) electronics. Further testing led to a make-before-break switching scheme. Implementation in the payload was accomplished by adding a second relay into each power transfer line and programming an appropriate controller switching sequence. Blocking diodes were incorporated to protect the battery during the make-before-break internal power switching.

Control problems were also identified during the development of operational procedures relative to the GN2 system. Concerns were related to accomplishing pre-launch pressurization of the low pressure tank and associated personnel safety during payload recovery operations due to the high pressure system. The solution adopted was to replace two of the check valves in the initial APM design with electrically actuated solenoid valves. Selective operation of the valves through the umbilical lines enable isolation of the high and low pressure tanks during pressurization. In addition, the SM controller will be programmed to open both solenoid valves, after the GTP is deployed, to equalize the pressure in both systems and allow eventual bleed-down through the low pressure system. Operating the valves from the controller console also enhances safety during test sequences in the event of a launch abort.

2.5.8 Component Selection

In selecting the microcircuits for the flight instrumentation preference was given to the components having JM8510 Class B qualification or DESC Standard Military Drawings. When unavailable or when excessive lead times were quoted the selection was made from the circuits listed under high-reliability products of reputable manufacturers. These components had to meet test requirements of MIL-STD-883 REV. C. Other electronic components were usually selected using MIL-STD-975F (NASA) as a reference. Only as a last resort, and in non-critical applications, commercial microcircuits and components were used.

Major electronic and electro-mechanical flight components were tested upon delivery and then subjected to environmental tests as prescribed by AFGL BBX Test Specifications. Shock and Vibration tests were conducted at AFGL's PVIF. Other testing was performed at ERL.

2.5.9 Diagnostics

Diagnostic instrumentation in the SM included a longitudinal accelerometer, a three-axis magnetometer, an ambient pressure transducer and signal conditioning circuits for thermistors located in the ogive APM and SM. A high resolution CCD camera adapted with a zoom lens is located at the forward bulkhead of the FPM. The real-time transmitted video will be used by the attitude control system joystick operator to locate and track the GTP after it is ejected. Control of the motorized zoom lens is also included in the up-link command console. An interface module was packaged in the SM to provide 12-volts from the 28-volt power bus for the camera. Switching relays were also included to reverse polarity for the 12-volt zoom lens motor.

Recorded video data will be useful as quick-look evaluation and post-flight analyses of the GTP performance. The up-link/television ground support system is discussed in Section 2.7.

2.5.10 IR Sources

This contract was tasked with assisting AFGL engineers in the development of an IR source to meet the design requirements defined by Boeing at the March Working Group Meeting. Initially the source, located on the forward bulkhead of the FPM, was defined as a simple heater element with a base plate. Investigations indicated significant thermal isolation problems and concerns with generating the required 800^{O}K temperature within the physical constraints of the space available on the deck plate.

Boeing estimated a 170 watt heater. Further thermal analysis dictated a 200 watt heater element and the need for a thermal insulator on the rear of the heater assembly. Figure 2.5.10 depicts the assembly, utilizing a Minco heater with a 2" alumina insulator compressed in a cylindrical frame. The

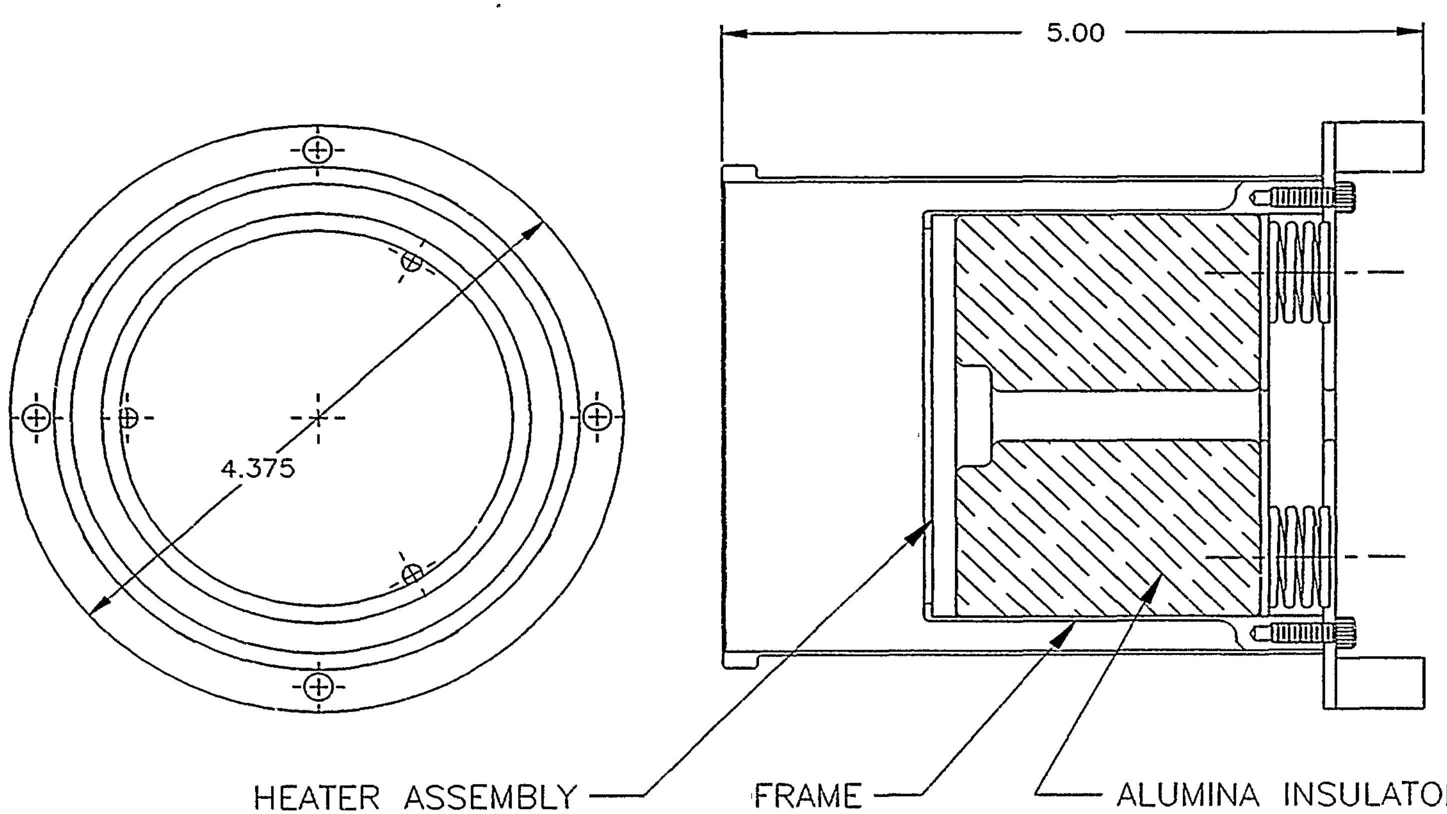


FIG. 2.5.10

LIFE IR SOURCE

outer shield indicated is a highly polished metal surface extending 1 1/4-inches above the surface of the heater element. A thermocouple was installed by Minco and wired to the PIM where Boeing will provide signal conditioning for a telemetry monitor.

A prototype unit was fabricated for evaluation and initial tests indicated the assembly met the temperature and isolation requirements. The heater element thermocouple measured a temperature of 1,100^{o}F after eight minutes of operation. Vibration and shock tests were then successfully completed to the Black Brant component levels. Another series of functional checks were conducted to investigate surface temperature (to correlate thermocouple data) operation in a vacuum environment and the effect of the outer cylindrical shield. The only negative result was oxidation of the copper surface at elevated temperatures. A secondary concern was the validity of surface temperature tests using a pyrometer due to the uncertainty of the emissivity of the copper. Studies and tests with several surface coatings led to a flat-black, high-temperature stove paint. Three applications of this spray paint on the copper produced a surface that survived repeated cycles to the maximum temperature.

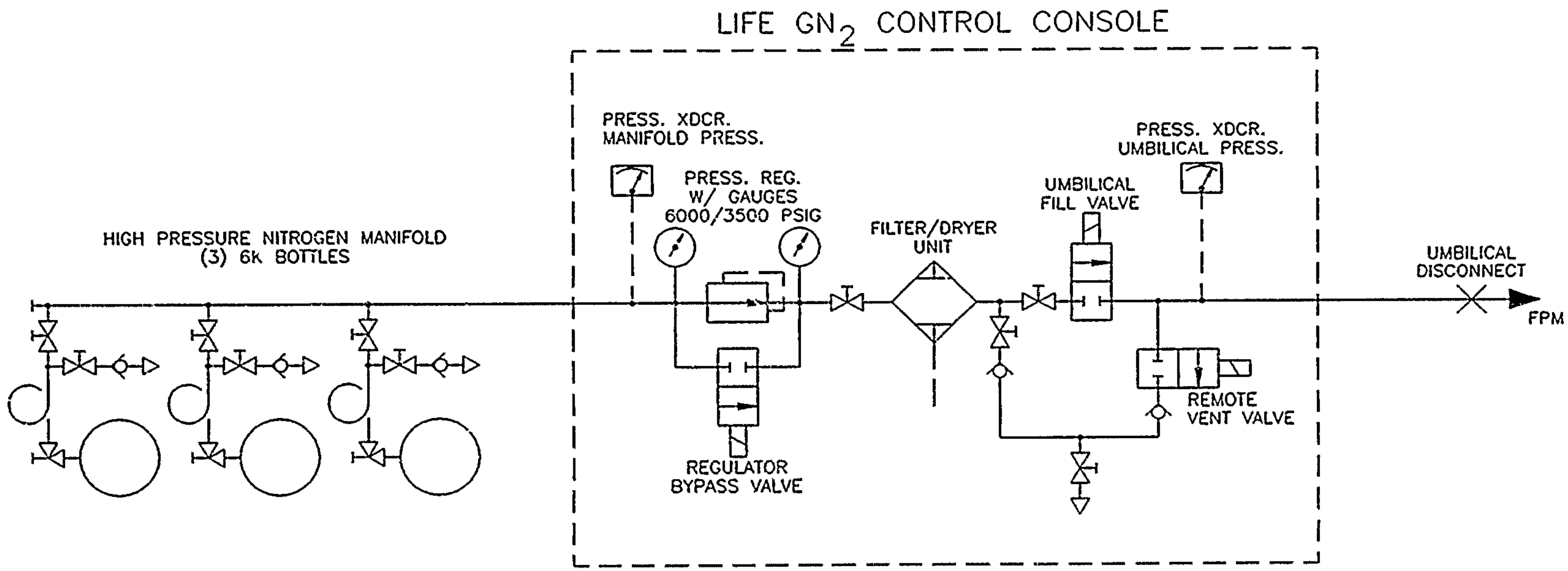
A second IR source was assembled, painted and cycled five times to insure durability of the surface. This unit was shipped to Boeing on 11 December 1990 for further testing in their laboratory with the LIFE GTP sensors. Favorable results were attained and they requested that the third assembly be prepared, using the same procedures, and be delivered to Boeing. Shipping occurred in early February 1991.

2.5.11 GN2 System

The GTP flight vehicle propulsion system, thermal battery and electronics required stringent temperature control. Early in the LIFE program thermal conditioning was on the Boeing side of the interface. After further analysis and testing by Boeing engineers this configuration was recogized as a major design and packaging problem. At the PCR, AFGL and ERL were tasked with developing flight hardware and ground support equipment to meet the specifications. This was the driving factor in the FPM/APM payload configuration described in Section 2.5.3.

Flight components, including two storage tanks, regulators, solenoid valves, pressure relief valves and a 200-watt heater assembly were packaged in the APM. Pressure and temperature sensors were included and conditioned through the Boeing interface module. A high-pressure, quick-release fitting was mounted on an umbilical bracket to connect the fly-away pressure line. One view of the plumbing layout is illustrated in the APM assembly drawing, Figure 2.5.3.1.

Boeing provided a conceptual design of the ground support system and the cleanliness requirements. Considerations were in operation in a test configuration, note control from the blockhouse and interfaces on the l[illegible]n pad. Figure 2.5.11 is a plumbing schematic of the GN2 support system showing the



NOTE: ALL TUBING TO BE 1/4" OD X .049 W. SEAMLESS CRES

FIG. 2.5.11

LIFE GN_2 SUPPORT SYSTEM

manifold and the launch pad control console. A rackmount shipping case was modified to house the control console components. Regulators, solenoid valves, check valves and related plumbing are mounted on the 19" x 23" front panel. The filter/dryer unit is mounted at an angle in the case, so that the filter element can be serviced by removing the rear cover. A 15' length of flexible tubing will be used for all pre-launch tests. At WSMR, the control console and manifold system will be located at ground level, approximately 15' behind the launcher. Implementation of the high-pressure tubing between the console and the launch rail at WSMR has not yet been resolved. A blockhouse control panel operates solenoids in both the payload and the pad control console. Pressure monitors are also included on the panel to confirm proper operation particularly during remote pressurization. Both consoles and the manifold system along with related cables and flexible tubing were shipped to Boeing on 20 December 1990. Cleaning and pressure checks will be conducted by Boeing personnel.

Several scenarios have been defined for testing, pre-launch operations, abort procedures and recovery of the payload. Safety is a concern during all phases when the GN2 system is pressurized. A vent valve is included in the ground control console which can be remotely actuated to bleed the system. Also, the final payload controller command in the flight sequence opens a series of valves to vent the payload pressure for recovery. This is only significant if the GTP is not ejected from the payload.

2.5.12 Recovery Module

ERL was tasked with servicing the LIFE recovery module. Bristol Aerospace part number 680-08700 is a recently modified version of the "17-inch aft para recovery system" developed for the Black Brant family of vehicles. Test procedures and engineering drawings have been reviewed, and a preliminary test of the system was conducted at AFGL. Final checks with flight batteries and the installation of pyrotechnic devices will be part of pre-launch operations at WSMR.

2.6 Support Systems

All of the programs discussed in the previous sections utilized flight hardware that is typical for sounding rocket support systems. The following is a summary of new concepts and design modifications incorporated during this contract period.

2.6.1 Batteries

As payloads have become larger and more complex, in-flight power requirements have increased significantly. For example, the BEAR payload required a total of fourteen (14) battery packs to support the accelerator/beam diagnostic and telemetry/physics systems. An open-frame, nicad battery pack was developed under the previous contract. In contrast to the sealed battery boxes, this design requires no potting material and is much easier to assemble and service. During this contract period F-cells (rated at 7.0 ampere-hours) in the same basic configuration, were qualified to Black Brant specifications. Test fixtures and automated test procedures for cells and battery packs were also developed and implemented during the BEAR program. Physical characteristics of the four open-frame battery packages are as follows:

CELL TYPE	AH RATING	W	L	H	WT
C_S	1.2	4.75 in.	7.10 in.	2.24 in.	4.16 lb.
1/2D	2.2	6.0 in.	9.25 in.	2.19 in.	6.75 lb.
D	4.0	6.0 in.	9.25 in.	3.05 in.	9.38 lb.
F	7.0	6.0 in.	9.25 in.	4.26 in.	13.75 lb.

2.6.2 PCM Encoders

During the period of this contract, the following innovations were made in the area of design of airborne PCM encoders:

1. EMI/EMC Protection

Analog and digital signal inputs, as well as power supplies, were provided with additional EMI/EMC protection because the high energy experiments aboard the payloads.

Where required, digital interfaces utilized optical coupling with high common mode rejection and voltage standoff capability to eliminate ground loop pickup of high energy pulses and the possible arc-over which may accompany them.

Analog inputs were protected by using differential input multiplexers with high voltage standoff capabilities as well as shunting the input lines to ground through fast zener diodes. In extreme cases, linear isolation amplifiers with voltage blocking ratings exceeding 5000 volts were utilized.

The input and output lines of the dc-to-dc converters were protected with coaxial-pi filters which offer high attenuation to the frequencies associated the switching of the converter as well as the transient pulses generated by the experiments.

2. <u>Programmable Array Logic</u>

With the availability of software (such as CUPL, ABEL and AMAZE) and programming hardware to produce custom digital circuitry, most new designs have utilized the cost effectiveness, space savings, and improved reliability of programmed logic devices. The cost effectiveness is due to fewer parts required in inventory as a single part can be programmed for many tasks. The savings in space results from the ability to program custom complex functions in a single package which previously took many standard packages to accomplish. Improved reliability comes from the reduction in external wiring needed to produce the required circuit.

3. <u>State Machine Controlled Encoders</u>

It has been found that the state-machine-controlled PCM formatter, in certain applications, has advantages over a microprocessor controlled formatter. The most important consideration is in speed capability. State machines can commonly generate instruction cycles at speeds in excess of 25 million instructions/sec, significantly exceeding that of microprocessors. The state machine formatter was used on the

BEAR, Boosted Aries, Spear I, and Life encoders. Another advantage of this type formatter is that it automatically recovers from momentary power interruptions as it needs no initialization cycle.

4. RS-232 Interface

The use of a standard RS-232 serial/digital interface has been used to transfer data from the Litton Inertial Guidance experiment to the PCM encoder. The interface used a standard Universal Asynchronous Receiver Transmitter (UART) to control the clocking and sequencing.

5. Housing

A new design in housing for electronic circuits which allows total access to the circuit board without removing connectors or removal from its mounting in the vehicle was designed during this contract period. Figure 2.6.2.1 show a drawing of this enclosure. This type of housing improves on the overall reliability of the flight systems since it eliminates much of the unnecessary removal and replacement of flight connectors and nearby components to troubleshoot difficulties or make late preflight adjustments. This housing was first used on the Boosted Aries project.

2.6.3 Payload Controllers

A second generation, microprocessor control system was developed and flown successfully on the BEAR payload. The controller is capable of 64 independent power switching outputs utilizing either an onboard timer program or a remote ground control computer through an RS-232 serial interface.

QUICK ACCESS BOX

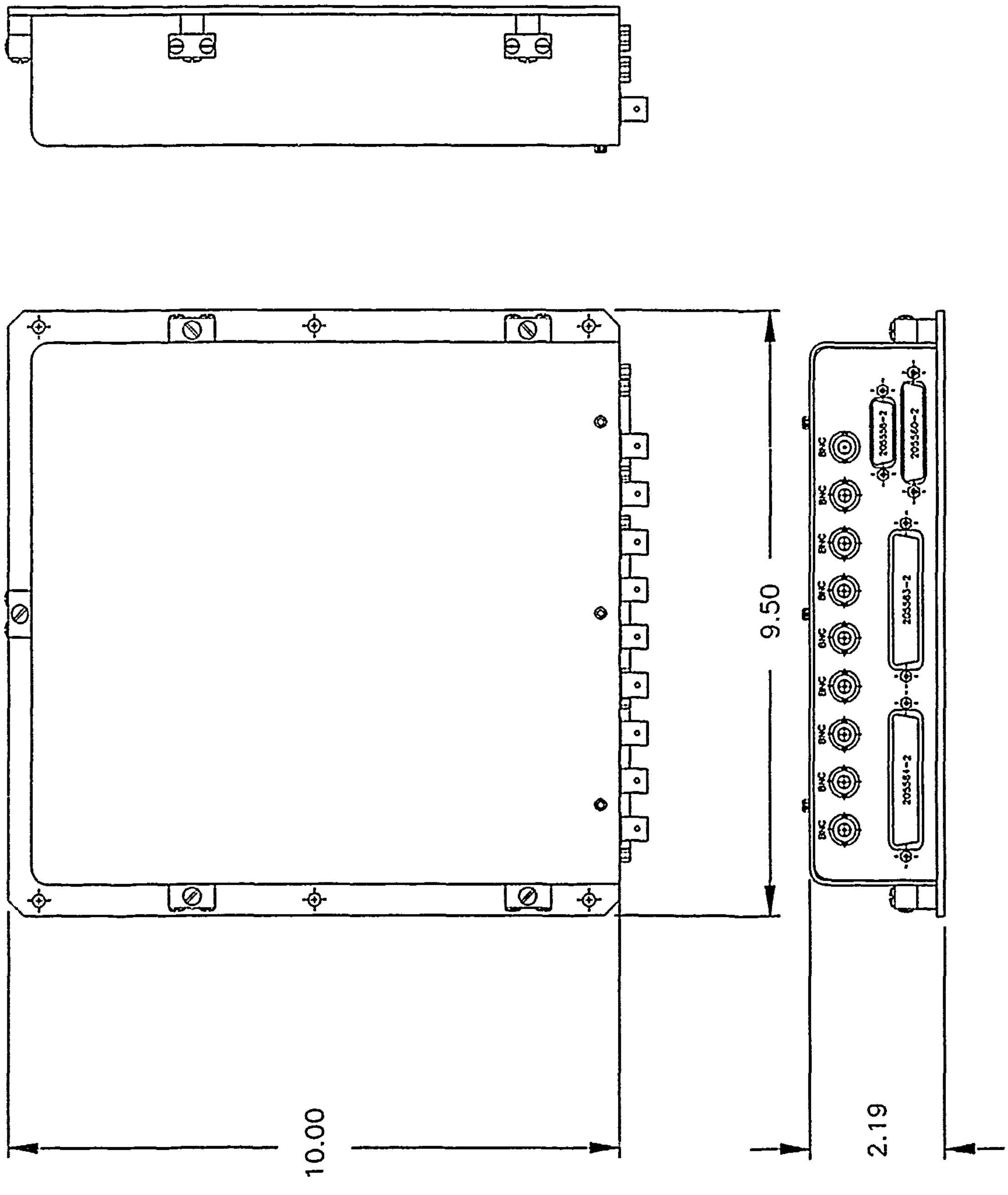


FIG. 2.6.2.1

The payload unit has a resolution of 100 ms and a total running time of approximately 1.8 hours, allowing control during a pre-launch countdown as well as providing in-flight functions. Ground control software allows each of the 128 signals (64 control/64 monitor) to be tagged with their functional names and displayed on the control computer screen. Control lines can be individually actuated, and/or test sequences can be uploaded over the serial communications lines. Umbilical requirements are reduced significantly with this concept.

Mechanically, the controller consists of four printed circuit boards packaged in a modular, busboard configuration. Capacity can be increased, in 64-function increments, by adding two input/output modules to the basic unit. A 6-module, 128-function system was used for environmental qualification testing. Redundance was accomplished in the BEAR payload by utilizing a second controller, operated from an independent power source.

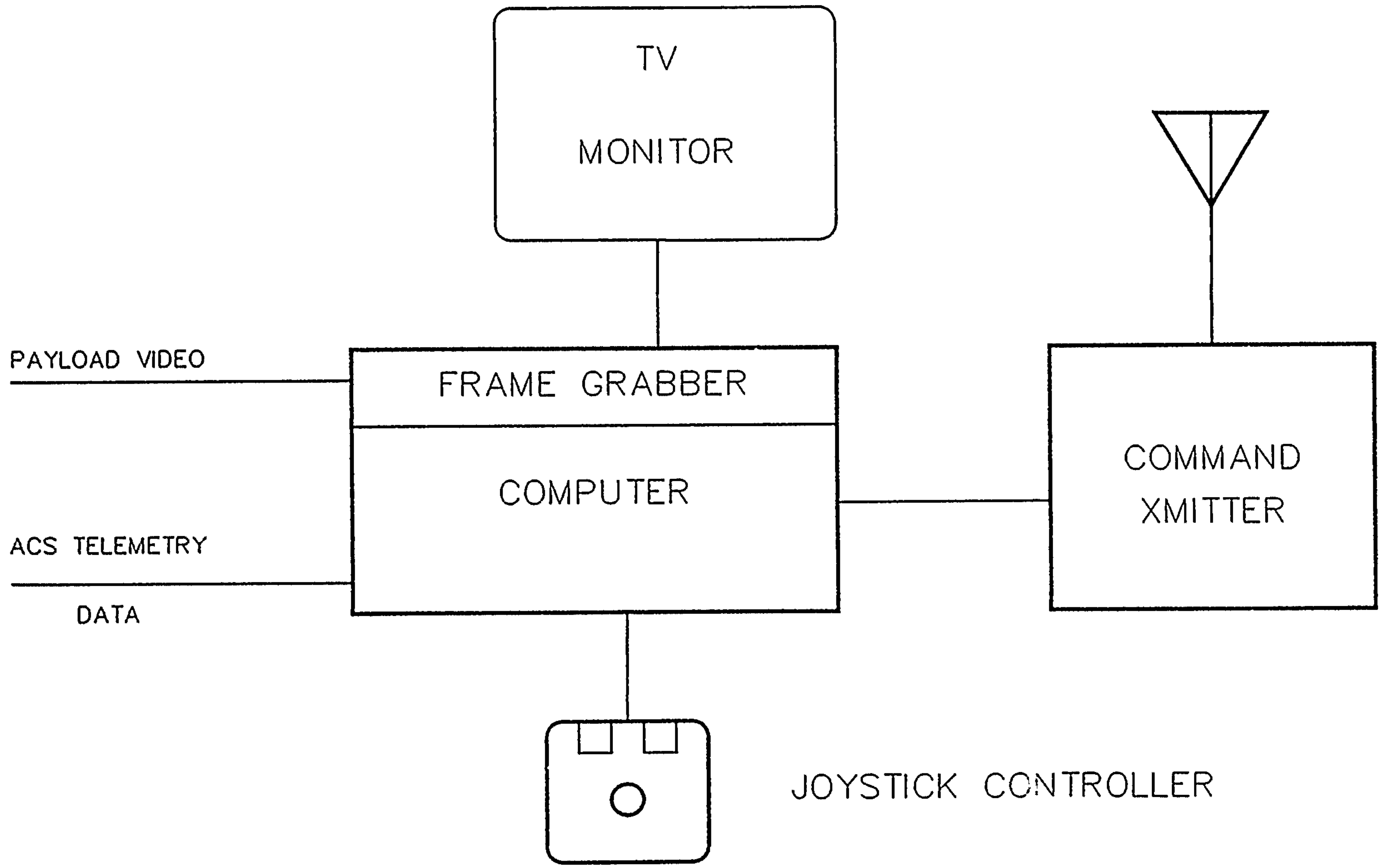


FIG. 2.7

UPLINK COMMAND

3.0 SHUTTLE PROGRAMS

3.1 IMPS

3.1.1 Background

The Interactions Measurements Payload for Shuttle (IMPS) was designed to carry several experiments/investigations. One of the investigations consisted of a group of instruments designated as the Environmental Interactions Monitors (EMI). The EMI Interface System (EIS) was designed to provide a single set of electrical interfaces between the EMI instruments and the avionics of the Shuttle Pallet Satellite (SPAS). The design of EIS was completed with a final Status Review held on December 2, 1987 at AFGL. Unfortunately, at that time, the entire IMPS program was terminated due to lack of funding.

The EMI consist a Suprathermal Electron Spectrometer (SES), a Pressure Gauge (PG), Electron and Ion Electrostatic Analyzers (ESA-E and ESA-I), a Differential Ion Flux Probe (DIFP), a Quadrapole Ion/Neutral Mass Spectrometer (QMS) and a cluster of instruments designated as Plasmas and Fields (PAF). EIS distributed power and commands provided time reference and directed the data flow from the instruments to the mass storage and the TLM link of the SPAS. Also included were control functions and circuits to provide deploy and retract commands for six E-Field Antennas (EFA) flown as a part of PAF.

The IMPS was designed to gather data in two modes of deployment. In the sortie mode the satellite remained in the cargo bay. Only few of the instruments collected data in this mode and thus the data volume was low. In the free flyer mode the satellite flew in formation with the shuttle. All of the instruments were active in that mode. A small, selected portion of the data, consisting mostly of monitor signals, were transmitted through the TLM link of the orbiter, while all of the data was stored in a recorder for post-flight processing.

3.1.2 Overview

The relationship of EIS to the EMI instruments and the avionics of SPAS is shown in Figure 3.1.2. The avionics of SPAS provided to each investigation one real-time data link to ground and one link for on-board data storage. EIS formatted the instrument data into the two serial digital streams. The data was formatted to conform to a subset of the International Packet Telemetry Standard. The EMI instruments providing digital data to the EIS were also required to divide their data into two digital streams according to the two final destinations. Discrete and analog data was processed by EIS and then inserted into the appropriate data packets. For instrument power, commands, and the real-time data EIS interfaced with the Modular Digital Universal System (MODUS) of SPAS. All data was transmitted to the Adaptation Kit (AK) which served as an interface for the tape recorder storing data from all investigations. The following paragraphs summarize the operation of the EIS with an emphasis on the

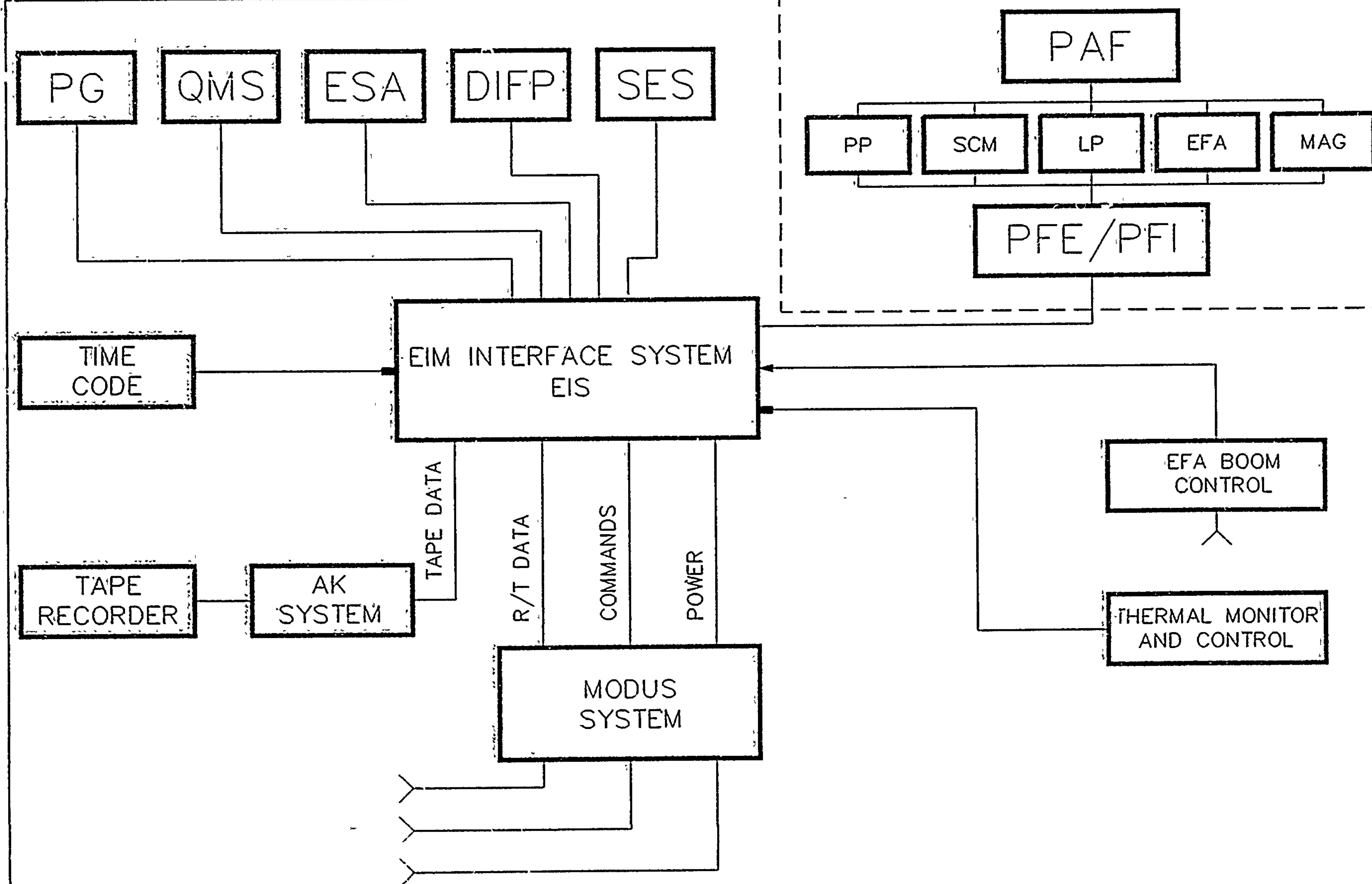


FIG. 3.1.2

EIM–EIS BLOCK DIAGRAM

changes that were incorporated since the PDR. A detailed explanation of the operation of EIS as it existed prior to PDR was offered in the final report "Instrumentation and Communication Systems for Sounding Rockets and Shuttle-borne Experiments", AFGL-TR-87-0139, 27 April 1987.

3.1.3 Real Time Data

The EIM investigation has been allocated a total of 1280 bps in the real-time data link of the Carrier. Each instrument and including EIS has been allocated 200 bps. A single packet of 2560 bits was formatted and transmitted to the Data Handling Subsystem (DHS) of SPAS at a constant bit rate once every two seconds.

The serial digital data from the instruments were requested and accepted in a burst at 16 kbps once every second. EIM was also allocated six 16 bit words for display on the Aft Deck of the Orbiter. Since the EFA's presented a possible hazard to the Orbiter, as well as, to the Carrier, the deployment data of the EFA's was displayed on the Aft Deck. Remaining bits were assigned to the QMS cover status monitors. This display data was transmitted as a part of the real time data.

3.1.4 Stored Data

A rate of 98 kbps of recorded data was allocated to the EIM during the free-flyer mode of operation. The allocation was reduced to 12.3 kbps for the periods of operation in the sortie mode. It should be noted that data transmitted through the real-time link are also included in the recorded data.

The transfer of the digital serial data from the instruments was under EIS control. Each 8 bit word was transferred in a burst of 64 kbps at a time. The word transfer rate for each instrument was determined by the data bit rate allocation for that instrument. The transfer control signals are synchronized to the Carrier clock.

The received data was formatted into 612 byte packets once every 50 ms in the Free-Flyer mode and once every 400 ms in the Sortie mode. Each packet was time tagged with Mission Elapsed Time (MET) data and transmitted to the Adaptation Kit (AK) of the Carrier for storage. The transfer rate of 512 kbps was controlled by the AK. EIS supplied only the packet ready signal.

3.1.5 Time Tagging of Data

Occasionally the Carrier avionics provided MET data to the investigation. This data transmitted as four separate 16 bit words of BCD and binary codes was stored until a sync pulse was received. From that moment the received MET data was incremented by EIS once every millisecond by a clock signal derived from the very stable Carrier clock.

At the start of each new packet the MET data was inserted into the secondary header. Since a well-defined time relationship existed between the insertion of the instrument data into the packet and the start of the packet formation the time reference for each data byte was established.

3.1.6 Commands

The EIM instruments have been allocated 32 unique 16 bit ground based commands. EIS uses 28 of these commands to satisfy a total of 108 commanded functions required by the instruments and the EIS. Serial digital, as well as, discrete commands are distributed to the instruments. Although only one command link is provided by the Carrier, for safety reasons, two separate receiver circuits process the commands.

To satisfy the EIM requirements, two ground based commands were combined to generate a single EIM command. The first command identified the instrument, while the second identified the task to be performed. To minimize probability of command confusion, the 8 bit codes selected for the commands had a distance of at least two bits from each other. Any code differing from the list of the expected codes was rejected, thus invalidating the whole command.

3.1.7 Power Distribution

The EIM system consumed approximately 87 watts of Carrier power. Twenty watts were reserved for EIS. All power circuits had two separately controlled relays: ENABLE/DISABLE and ON/OFF. All power lines were fused. Each fuse was shunted by a diode-fuse combination for reliability.

3.1.8 EFA Control

The deployable EFA's constituted a safety hazard. Accidental deployment within the bay of the Orbiter may have impaired some vital function or done damage to the structures and/or personnel in the vicinity. Also, failure to retract would require separation of the antennas from the Carrier before the retrieval. Safety requirements dictated three independent power interrupts, one of which should be non-rf controlled. Since external connections to the Carrier were not under EIS control, only the two r-f controllable interrupts were provided by EIS. In addition, separate fusing was provided for the deploy and the retract circuits to insure that a malfunction during deployment could not prevent retraction of an antenna.

In the signal section of EIS, two separate command processing circuits were employed. The flow of the "ENABLE" commands and the "EXECUTE" commands became independent once the command arrived at the EIS and was processed by the two circuits. Thus, two independent interrupts were implemented.

3.1.9 Components and Materials

Electronic components and materials were selected according to IMPS Policies and Requirements Document (PAR). Microcircuits were selected mostly from MIL-M-38510 listing. When unavailable in that listing, selection was made from the circuits listed under high reliability programs of reputable manufacturers. The selected components met test requirements for Class B, Method 5004 of MIL-STD-883 Rev. C. The selection process for the microcircuits also eliminated components which were known to exhibit single event upsets and/or latchup in space environment. Other electronic components were selected from MIL-STD-975F.

3.1.10 Isolation, Grounding and Shielding

The signal and the power grounds were isolated. Since EIS served as an interface for the EIM, instrument signal and power grounds terminated at EIS. There a common single wire connection was provided between signal and the chassis grounds. The grounds of the EIS were connected to the star ground of SPAS. The signal paths from EIS to AK and EIS to DHS were optically isolated.

All cables connecting EIS to the instruments had an overshield which terminated at the back shell of the connectors. These practices met the requirements of the ICD.

3.1.11 EIS Housing

Aluminum 6061T6 was selected as the material for the EIS electronics box. The design excluded welded seams and incorporated features to prevent fracture propagation. Threaded inserts were used for screws and dimensional variations due to heat were accommodated. The PC cards containing electronic components were mounted in locking card guides and were restrained on all four edges.

3.1.12 Reliability and Quality Assurance

A reliability and Quality Assurance plan in accordance with JPL-D-2836 was required. The plan included: reliability analysis, parts and materials selection and control, procurement control, fabrication, inspection and testing. Handling of parts and equipment, storage, shipping transportation and configuration management were included.

3.1.13 Ground Support Equipment for EIM/EIS

To support EIM integration Application Specific Test Equipment (ASTE) was necessary. The individual EIM investigations were expected to provide their own test equipment to verify the integrity of the instruments. During the integration proper interaction between the EIS and the instruments had to be verified. Therefore, a design of an ASTE transparent to the instruments was completed.

Instrument test equipment connected to the ASTE saw the data, delayed by one packet formation period, in the same sequence and format as it has been taken from the instrument by the EIS. The exception was the control of the data flow. While connected directly to their instruments, the individual test equipment controlled the data flow, presumably simulating EIS. When EIS was interposed between the instruments and the test equipment, the EIS assumed the control of the data flow. Thus, overall synchronization was maintained.

MET data simulation was also included in the ASTE design and was available as a serial burst or as a parallel output during the packet read period.

Readout of selected packets was also available on IEEE-488 interface. Packets reproduced from a recording medium and transferred to EIS were also available to the instrument test equipment.

To test the EIS in the absence of EIM instruments, an EIM simulator was used. Under external control the simulator provided test data patterns to be processed by EIS.

3.2 IBSS

The Infrared Background Signature Survey (IBSS) experiment scheduled for launch on STS-39 in March 1991 consists of a Chemical Release Observation experiment (CRO), Critical Ionization Velocity experiment (CIV), Infrared Sensor (IRS), IRS - Optical Instrument, Low Light Level Television Camera (L^3TV) and Arizona Imager/ Spectrograph (AIS). With the exception of CIV the experiments are carried by the Shuttle Pallet Satellite II (SPAS II) and will fly in formation with the shuttle during the experiment. CIV will remain in the cargo bay.

ERL supported the AIS and CIV experiments. Data handling interface and data storage devices were supplied to AIS. In addition to data handling, storage, and experiment control, ERL had the responsibility to condition and to distribute the shuttle power to the CIV instruments.

Evaluation of a proposed television video link between the orbiter and the IBSS payload was also undertaken on behalf of AFGL. The link was intended for visual observation of the orbiter from the SPAS. The evaluation included interference tests between all radio frequency links on both the shuttle and the SPAS. The tests results were presented by NASA in reports EE-88-702 and EE-88-203.

3.2.1 CIV Instrumentation

3.2.1.1 Background

During the experiment four gases (NO, Xe, Ne, and CO_2) will be released from the bay of the shuttle in the direction of RAM to verify the Critical Ionization Velocity theory. Located next to the Gas Release Subsystem (GRS), the Monitor Electronics Subsystem (MES) will measure the plasma temperature, density, potential, turbulence, and emitted radiation. Additional data will be obtained from sensors located on the SPAS released from the shuttle for standoff measurements. The PSS, as shown in Figure 3.2.1.1, will serve as the power interface between the shuttle, the MES, and the GRS. It will also control the gas release sequences and time-tag and record the MES data for correlation with the data from SPAS.

The CIV experiment has been integrated, tested and installed into the bay of the orbiter. The flight is scheduled for March 1991 on the Discovery.

3.2.1.2 PSS Overview

Four functionally distinct blocks of electronic components are packaged in a single hermetic container. Power circuits encompass fusing, conditioning, distribution and the dc/dc converters for the PSS circuits. The control circuits provide timing signals, gas release control, evaluate PSS and gas bottle status monitor information and control the data recorder. They also interface with the Standard Switch Panel

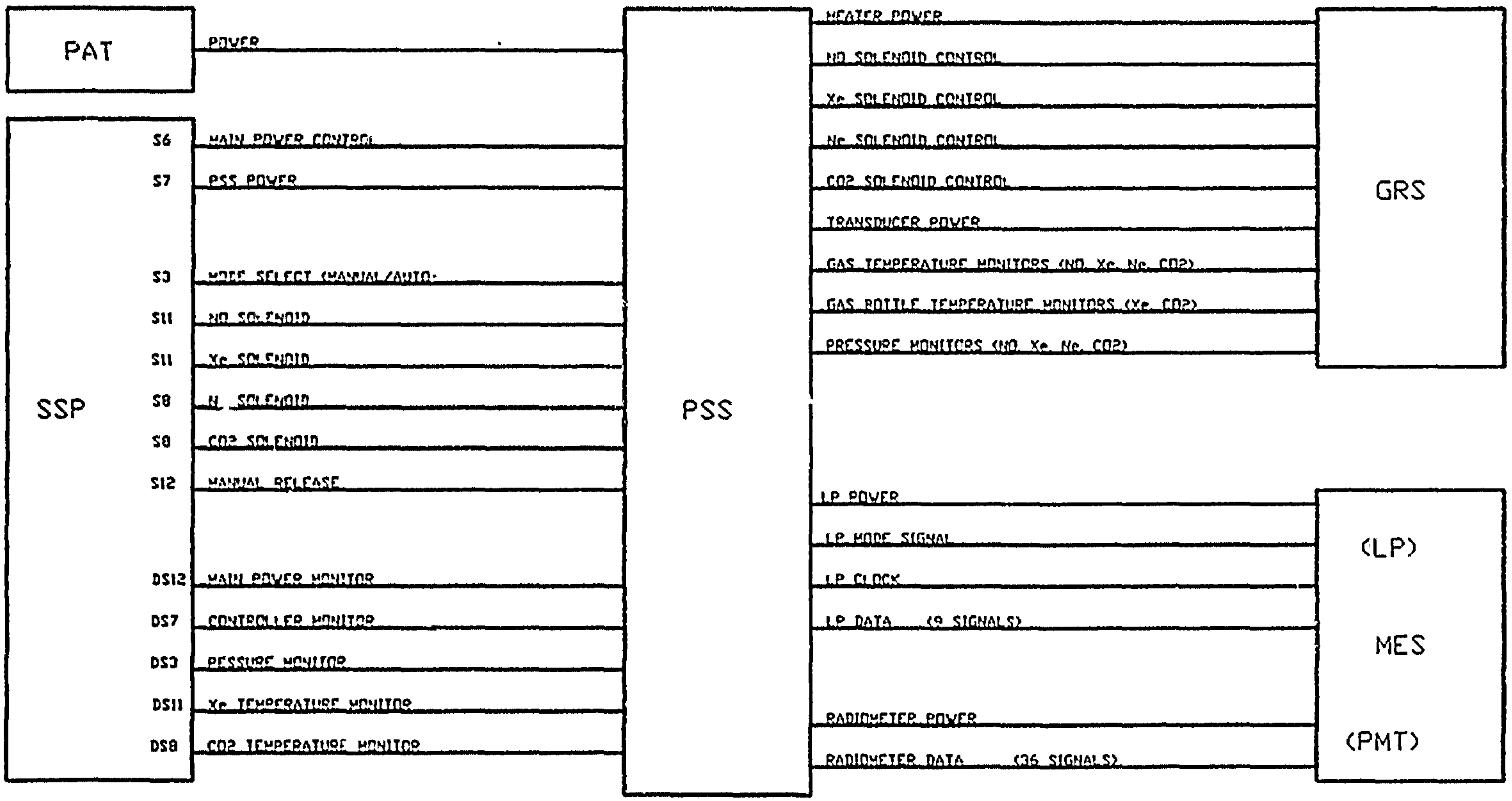


FIG. 3.2.1.1

PSS: CIV INTERFACE

(SSP) of the orbiter for commands and to transmit the status information. Data handling circuits perform analog-to-digital conversions, format the data, insert time codes and facilitate data transfer into storage. Finally, a ruggedized optical disk unit serves as the data storage. A block diagram of PSS depicting the internal relationship of the major functional blocks is presented in Figure 3.2.1.2.

3.2.1.3 Power

PSS receives its power from the Power Accommodation Terminal (PAT) of the shuttle and distributes the power to the electronics of the GRS and MES and to the heaters of the gas bottles containing Xe and CO2.

3.2.1.3.1 Fusing

All power lines entering and leaving PSS are double fused with the back-up fuse disabled under normal operation by a diode drop. (This also holds true for all control and monitor lines to SSP except where SSP supplies the power.) The main power fuses contain additional diodes to protect the power conversion circuits from the negative power transients specified for the cargo bay power bus. The reliability of fuses is maintained by using derating factors while preventing overdesign and possible problems created by "smart shorts". The fuse sizes are specified using a derating factor of 0.21 for lines carrying maximum current of 210 mA or less. One ampere fuses are employed in circuits carrying currents between 0.21 and 0.46 A. All other circuit fuses have a

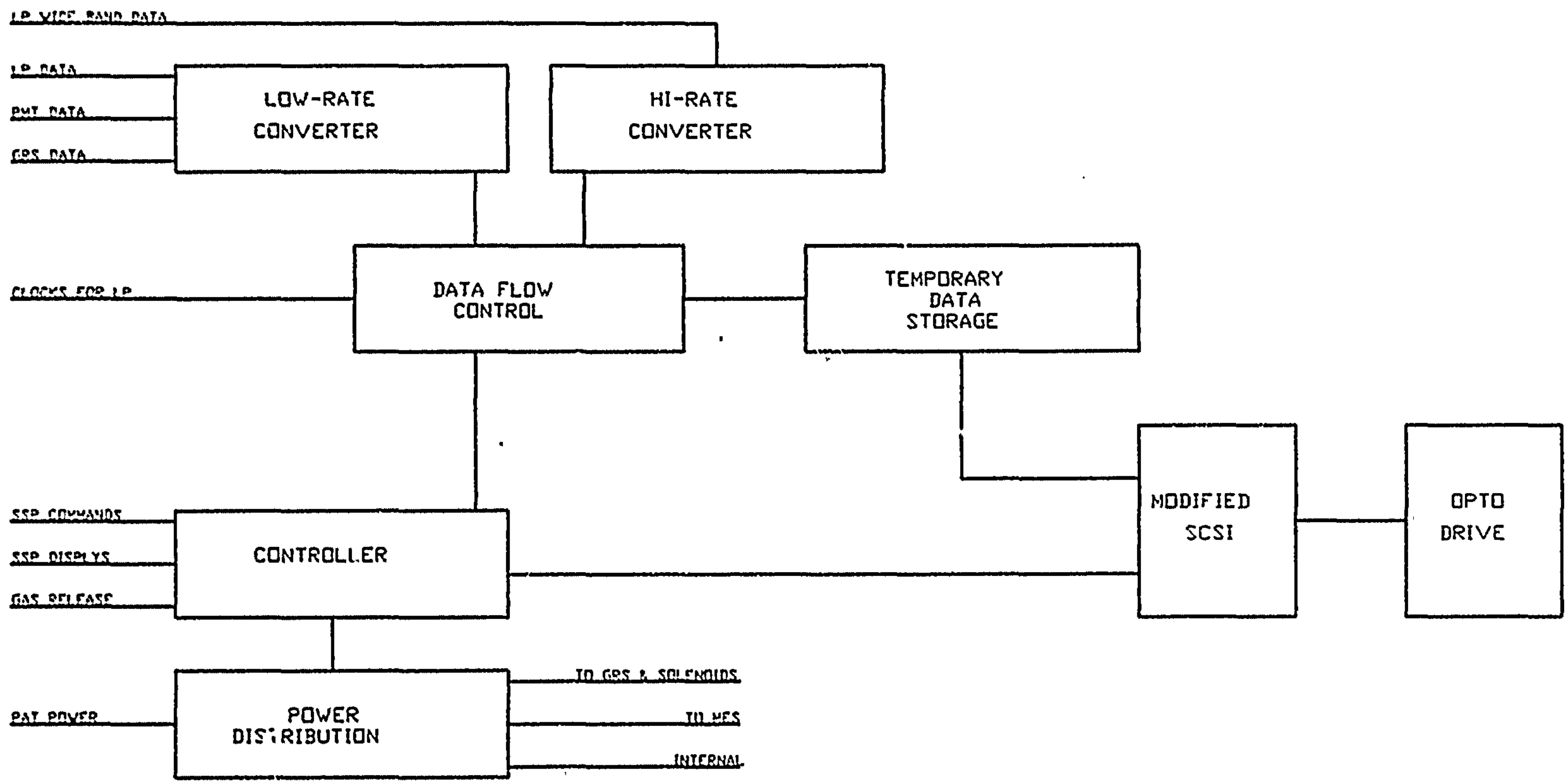


FIG. 3.2.1.2

PSS BLOCK DIAGRAM

derating factor of 0.46. The fuses selected from the approved fuse list (MIL-STD-975F NASA) have ratings as close as possible but not less than the specified value.

3.2.1.3.2 <u>Pre-regulation</u>

All power lines supplying power to the PSS power converters are pre-regulated to approximately 23 V. This minimizes the effect on the dc/dc converters of the occasional 500 to 700 Hz oscillations produced on the bus by the operation of the Hydraulic Circulation Pump of the orbiter. The pre-regulators also offer additional protection for the dc/dc converter circuits against the possible +56 V pulses superimposed on the nominal bus voltage. At the request of the Air Force the power circuits for MES and GRS were retro-fitted within the PSS with pre-regulators for protection against these positive transients.

3.2.1.3.3 <u>Converters</u>

Power needs of the PSS are supplied by four dc/dc converters. The optical disk drive requires +12 and +5 volt supplies while the other circuits use +/- 15V and +5V. Although a single 5V supply could satisfy the power needs of both subsystems, for reliability two separate supplies are used to keep the power of each below the 75% level of the full power rating. The PSS converters as well as the pre-regulators are mounted on heat sinks and operate within a few degrees of the ambient temperature. All input and output lines contain EMI filters.

3.2.1.4 Control

A "watch dog" protected CMOS microcontroller with some HCMOS support IC's perform the control, command, and timing functions during the experiment.

3.2.1.4.1 Watch Dog

The watch dog circuit resets the uC when a defined set of instructions in the program fail to be executed. These instructions have been selected to minimize the possibility that an accidental loop within the program could follow a path without returning to normal operation while escaping detection. Damage to timing and control sequence after a crash is minimized by checking certain parameters within the internal registers of the uC which usually are not affected by a reset. When a total of 8 resets occur during a gas release sequence, system failure signal is sent to SSP. The experiment may proceed under manual control and may continue to be observed from the SPAS, but the data of the MES instruments will not be recorded.

3.2.1.4.2 Gas Release

Automatic or manual gas release is possible. Automatic release is the primary mode of operation. The automatic release sequence is initiated by the first switchover at SSP from manual into the automatic mode after power-up. At that time the "stop watch" counter that controls the release timing is activated. The sequence starts with a 70 second background observation followed by a 10 second release of the first gas.

After the release of each gas an interval of 20 seconds is allotted for observation before the next gas in the sequence is released. The gases are released in the following sequence: NO, Xe, Ne, and CO_2. The final release is followed by an observation period of 430 seconds. At that time the recording of data is terminated and a signal marking the end of that release sequence is provided to the mission specialist operating the SSP. Although the AUTO release sequence may be interrupted and manually executed from SSP, the "stop watch" circuit and the recording of data can not be stopped except by a system shutdown. Returning to AUTO mode continues the release sequence from the time of the return. Relay closures provide the power to the solenoids of the gas release valves in the GRS.

3.2.1.4.3 Status

The controller provides the PSS and the gas bottle status information to SSP. Due to a limited number of monitors available on SSP, only four monitor signals are employed. Two monitors are used for the heated gas bottle temperature, the third indicates a combined bottle pressure status, and the last one conveys the status of the PSS. The nozzle pressure of each gas is sampled 10 times per second. Samples taken during the first two seconds of a gas release and the three seconds during the gas shutoff are ignored. At other times, three consecutive out-of-range pressure sensor samples of any gas prompt the controller to latch the pressure indicator on the SSP into OFF state. Switching into the manual mode turns the indication ON again. When a gas is released in the manual mode and the pressure is within range the indicator switches OFF for the duration of the release.

3.2.1.4.4 Recorder Control

When power is first applied to the PSS in the manual mode, the controller issues a number of commands to initialize the optical disk recorder. After the PSS operation is switched into the AUTO mode and data for recording becomes available, the controller issues commands to record 15 sectors (7680 bytes) of data at one time. The write commands are repeated until all of the available data has been recorded. Then the controller waits, performing other tasks, until a new data block becomes available. If a write error occurs, the controller instructs the recorder to advance a prescribed number of tracks and try again. If eight such recording attempts fail or if the 10 minutes allowed for the data recording have elapsed no further attempts to record are made during that gas release cycle.

3.2.1.4.5 GSE Interface

PSS can also be operated in an external control mode. This mode was incorporated to facilitate testing and diagnosis during the development stages. It is entered whenever the controller senses an external circuit at an interface connector provided for that purpose. In this configuration the controller acts as an interpreter of external commands transmitted from PC over a modified RS-232 link. Thus gas release commands may be executed or the data recorded on the disk may be accessed for read-out.

3.2.1.5 Data

MES, GRS sensors and some of the monitors within the PSS generate analog data. A total of 72 analog signals are converted into digital format using 12 bit resolution. The sampling rates vary. One signal must be sampled at 20 ks/s for one second every three seconds, while other sampling rates range from 250 s/s to 1 s/s. Two separate A/D's are used. The converted data is first placed in a temporary storage in a standard PCM format and then transferred onto the optical disk.

3.2.1.5.1 High Rate Converter

A stand-alone 12 bit converter is employed to sample the one signal requiring 20 ks/s sampling rate. Once every three seconds a synchronizing signal initiates a conversion run of 20 k samples. This conversion cycle coincides with one of the modes of a Langmuir Probe (part of MES) which also is controlled by PSS data conversion circuits. The support circuits driven by a program stored in PROMs have a direct access to the RAM where the data of each conversion is stored in an appropriate location for the PCM format. Once the signal sampling run is completed, some locations in the last minor frame that normally would be filled with the hi-rate data remain empty. Those locations are then filled with calibration voltage data sampled and converted by the same A/D converter.

3.2.1.5.2 <u>Low Rate Converter</u>

The circuits employed for the A to D conversion of the rest of the signals are uP driven. HCMOS circuits, supplemented by fuse link CMOS PROMs to store the programs, are used to implement the necessary control functions. The conversion rate of 1000 s/s is more than adequate to meet the system requirements.

3.2.1.5.3 <u>Data Formatting</u>

Abundance of equipment to handle a standard IRIG PCM was the driving reason behind the choice of the PCM format for the CIV data. It was recognized that the Packet format required less mass storage space and presented no difficulties to the computerized data reduction after the mission. However, the ease with which the PCM data could be handled by the available equipment during the development and testing stages of the program outweighed the advantages of the Packet. Data storage space also was more than adequate to accept the larger overhead of the PCM format.

Two 64k x 16 RAMs are employed for data formatting and temporary storage. Three seconds of data are formatted into one major frame consisting of 150 minor frames. Each minor frame contains 269 twelve bit words including a 24 bit sync pattern, and minor frame counter. To help data sequence identification and correlation of the data taken by the SPAS instruments, Real Time Clock data, Stop Watch data and a Major Frame counter are included in the data stream.

While the incoming data is stored in one of the two RAMs, the data from the other RAM is transferred into the optical disk recorder. Each data word stored in the RAM has a four bit word length specifier attached to it. This is used to control the stored data conversion into the eight bit words necessary for the optical disk recorder.

3.2.1.5.4 <u>Optical Disk Recorder</u>

The 200 M byte Write Once Read Many times (WORM) disk has been mapped into six test and eight flight data files. Each test file dedicated for pre-flight checks can hold over 4 M bytes (over 3 minutes) of data. These files can only be accessed using GSE. Each flight file can hold nearly 17 M bytes or over 13 minutes of data. SCSI interface is used to transfer data from the temporary memory to the disk controller.

In the flight configuration the PSS controller searches for the first unwritten flight file to record the data. The transfer of the data from the RAM to the recorder takes slightly over two seconds. It is executed as eight separate transfers in blocks of 7680 bytes each. The last 690 bytes of data are filler material introduced for convenience. The filler contains AAH or BBH depending on the RAM from which the data has been transferred. The same material is used to fill the spare words within the PCM frame.

In the event the recorder is unable to write data in the primary sector it tries to record the data in alternate disk areas. If successful this process is transparent to the user. In case of failure, the recorder informs the PSS controller of its inability to write. The PSS controller then issues commands to try once more 150 sectors removed from the original sector in which the failure occurred. Five such failures within a gas release cycle stops any further attempts to record. Other functions of the release cycle remain unaffected and continue to completion.

In the unlikely event that, due to excessive number of bad sectors and/or seek operations, the data transfer can not be completed before the RAMs switch, steps are taken by the PSS controller to minimize the data loss by re-synchronizing the data transfer process during the next transfer interval. The remainder of data in the old RAM is lost. In its place the data from the new RAM is recorded until the execution of the old command is completed. A new command for appropriately abbreviated data transfer is then issued. The data recording returns to the normal sequence after the next RAM switchover.

3.2.1.6 PSS Enclosure and Interface

The PSS electronics are enclosed within a rectangular hermetic enclosure with provisions for purging and 10 hermetic connectors. The enclosure was supplied as a GFE to ERL.

Internally the enclosure is divided into three major sections: optical disk drive, power distribution modules, and encoder/controller printed circuit cards. Five modules are used for power distribution components: fusing, relay, pre-regulator, optical disk drive power converters and filters, and encoder/controller power converters and filters. The encoder/controller components are mounted on 11 printed wiring boards interconnected through a backplane board. All of the modules are connected by a harness.

ERL also supplied the flight cables between PSS and MES. All other flight cables were supplied by other sources.

3.2.1.7 Grounding, Shielding and EMI

The CIV instrumentation maintains separate signal and power grounds. All grounds are connected to a single star ground within the PSS. The star ground is connected to PSS enclosure. With the exception of the Langmuir Probe all other enclosures are not connected to the ground wires. Since the case serves as the return for the Langmuir Probe it must be connected to the signal ground. Analysis indicates that the effect of the resulting ground loop on other instruments is minimal.

ERL supplied cables are shielded with the shields attached to the cases. Also, portions of the internal harness deemed to be susceptible and/or possible generators of EMI have been shielded. Power line filtering was previously mentioned. In general, every effort has been made to insure that the PSS meets the conducted, radiated and susceptibility requirements specified in the ICD for CIV.

3.2.1.8 Reliability and Quality Assurance

In the design and construction of PSS all safety, interface, construction, and materials requirements were met. To assure reliability guidelines stated in " Reliability and Product Assurance Guidelines For Government Furnished Instruments On The Infrared Background Signature Survey (IBSS) Program" issued by SDIO were followed.

3.2.1.8.1 Electrical Components

In selecting the microcircuits for the CIV instrumentation preference was given to the components having JM8510 Class B qualification or DESC Standard Military Drawings. When unavailable or when excessive lead times are quoted the selection was made from the circuits listed under high reliability products of reputable manufacturers. These components must meet test requirements of MIL-STD-883 REV. C. The selection process also eliminated components which are known to exhibit single event upsets and/or latchup in space environment. Notable among those are the EPROMS sometimes used in orbital applications to store uP programs. Although admittedly rare in properly designed enclosures, a single bit change in an EPROM stored uP program, caused by a stray cosmic ray, ruins the whole experiment. The cost difference in using fuse link PROMS in place of EPROMS is more than justified by the increased reliability. Other electronic components were selected using MIL-STD-975F (NASA) as a reference. Only as a last resort and in non-critical applications commercial microcircuits and components were used.

3.2.1.8.2 Environmental Testing

Environmental testing of PSS was performed at AFGL PVIF to the CIV program requirements. ERL personnel supported the testing. All requirements were met.

3.2.1.9 GSE

To support PSS testing and performance evaluation a number of GSE modules and interconnecting cables are used. They include a number of signal simulators, data conditioning circuits, and a PC with task specific software.

During system tests the PSS burst data is converted into a continuous PCM data stream by an Adaptation Kit to be used in conjunction with standard PCM decommutators. Recorded data also may be read from the disk and displayed on a monitor screen. The latter process is cumbersome since the normal operation of the system must be interrupted. It is usually employed after a test has been completed to verify that data has indeed been properly recorded. The PC can also be used to exercise the system by-passing the programmed flight control.

3.2.2 AIS Interface

ERL provided an optically isolated interface between the AIS and two Sundstrand Data Control, Inc. Data Loggers - miniature digital data recorders. Block diagram of the interface is shown in Figure 3.2.2. The data generated by AIS was sent in a serial form at 230.4 kbaud per second rate. The format contained one START, one STOP and no PARITY bits. A UART converted the data into eight bit parallel words for

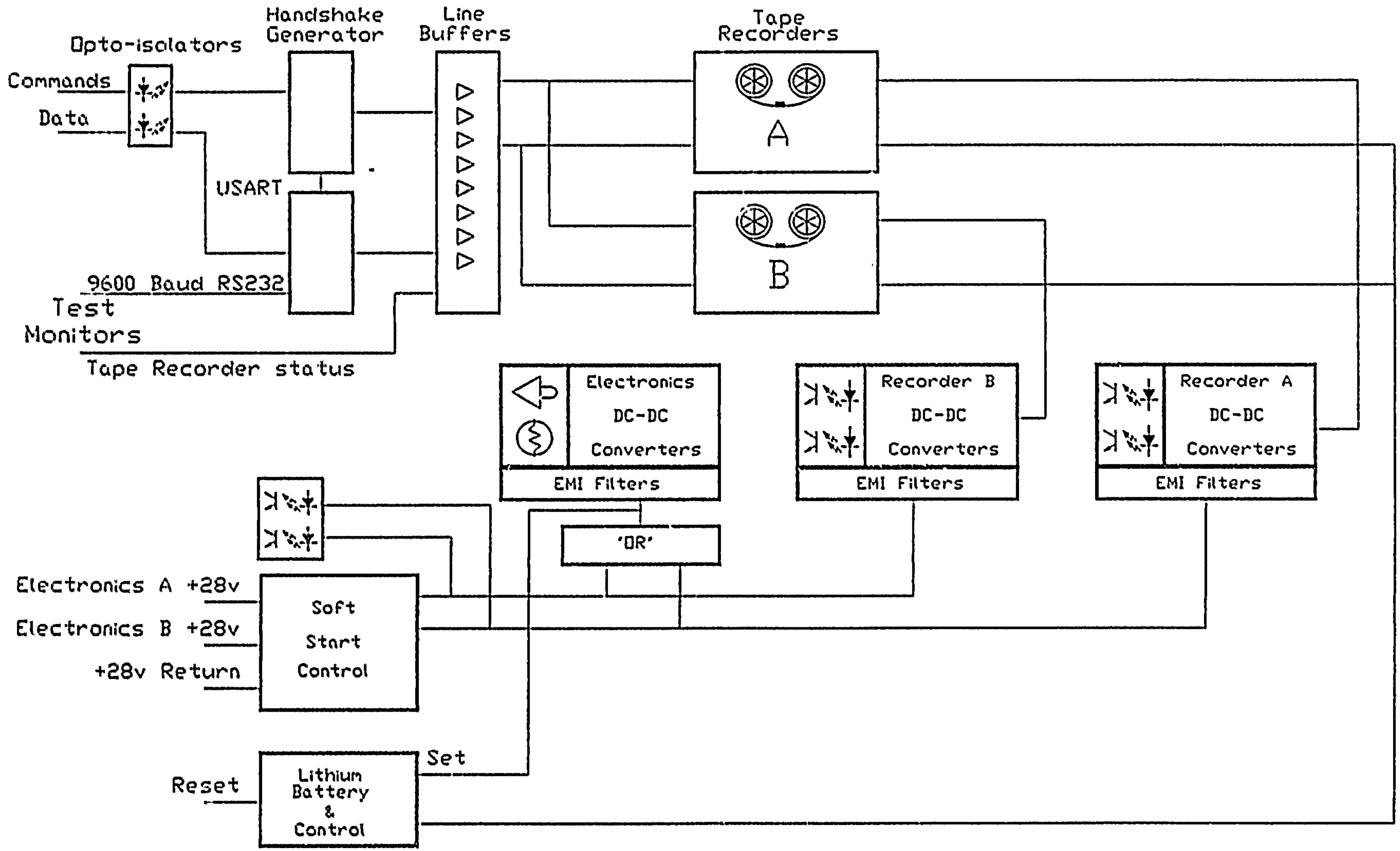


FIG. 3.2.2

AIS INTERFACE BLOCK DIAGRAM

transmission through a modified RS-422 signal interface to the recorders. Appropriate 54HCTXXX circuits were used to provide a differential 5 volt drive for the data as well as the control signals. Circuits from the same logic family were also used to implement single ended receivers to monitor recorder status and handshake signals.

An interface to monitor performance during testing has been included. The transmitter already present in the UART augmented by an RS-232 driver were utilized to provide 9600 baud per second data rate to GSE. The status of the data logger or the data being transmitted to the logger could be selected for viewing by a switch in the GSE. Since the incoming data rate to the recorder by far exceeded the monitor link capacity, only random samples of the data were available for inspection. The RS-232 interface driver circuits were automatically deactivated by interrupting their power upon removal of the GSE connector. This feature was incorporated to enhance system reliability during the flight.

The two recorders were capable of storing in excess of 300 Mbits of data each. The data transfer rate of 184.32 kbps executed during the experiment was comfortably below the maximum specified rate of 230 kbps. AIS maintained the control over the selection of the recorder and its basic functions. Selection was made through the application of power. TAPE INHIBIT, TAPE ENABLE and SELF TEST commands originated in AIS as two bit codes. The interface subsystem interpreted the codes and conveyed the appropriate control signals to the recorder. Once initiated the data transfer to the recorder and the necessary handshakes were under the interface circuit control. The WRITE command instructing the data logger to record its partially filled buffer (usually executed at the end of data transfer) was transmitted as a separate signal by AIS. The interface provided only optical isolation and the driver circuit.

A lithium battery in the interface subsystem was used to power the tape direction memory circuits of the tape drive. The capacity of the charge storage circuits in the recorder was inadequate to power these circuits during the long periods between the experiments. To accommodate the external battery some modifications within the recorder were made. Also a latching relay was incorporated into the battery circuit. The relay could be externally reset. In that condition the battery was disconnected from the tape drive circuits. Once the interface subsystem received power the relay reconnected the battery. Unless an external reset was once again applied, the battery circuit remained active. Thus the battery life could be extended while waiting for the experiment to begin.

Power for the tape drive control and recording circuits was supplied by the interface subsystem. After some component failures were experienced with three of the drives, circuits were introduced to control the turn on sequence of the dc/dc converters supplying the power. The sequence +5V followed by +/- 15V and then +28V separated by some delays eliminated the encountered problems. Inquiries directed to other users and the manufacturer did suggest that the +5v supply should be turned on before the +28 volts are applied to the drive (suggestion not mentioned in the available literature at that time). Another failure of the same nature was experienced after this modification. Only after the turn on times of all three supplies were spaced no more failures were experienced.

3.3 GAS/VIPER

VIPER is a Visual Photometric Experiment that will be flown as a part of the standard Get Away Special (GAS) system. The GAS system is available for small self-contained payloads to fly aboard the Space Shuttle. Air Force Geophysics Laboratory in conjunction with Northeastern University under previous contracts has designed a payload support system for the GAS/VIPER payload.* This system basically consists of a rack structure, a programmable payload controller, a data acquisition system, a data recorder and a power system. The system block diagram is shown in Fig. 3.3.

3.3.1 Mechanical Structure

There are two standard rack designs available for the payload support system. The first divides the available space into two cylinders. The support electronics are mounted in the bottom cylinder. The top section is available for the experiment. The second design divides the area into two semi-cylinders with the support electronics mounted to one side and

*Final Report No. AFGL-TR-87-0139 under Contract F19628-83-C-0037, dated April 27,1987 and Final Report No.AFGL-TR-87-0241 under Contract F19628-81-C-0029, dated July 1987. ADA199687

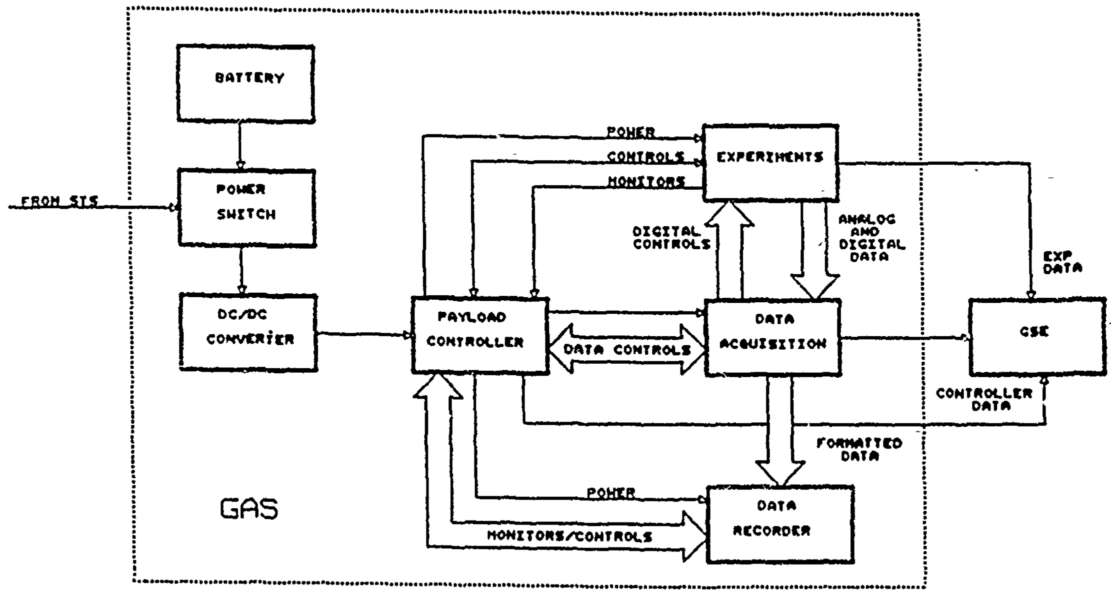


FIGURE 3.3 GAS PAYLOAD SUPPORT SYSTEM

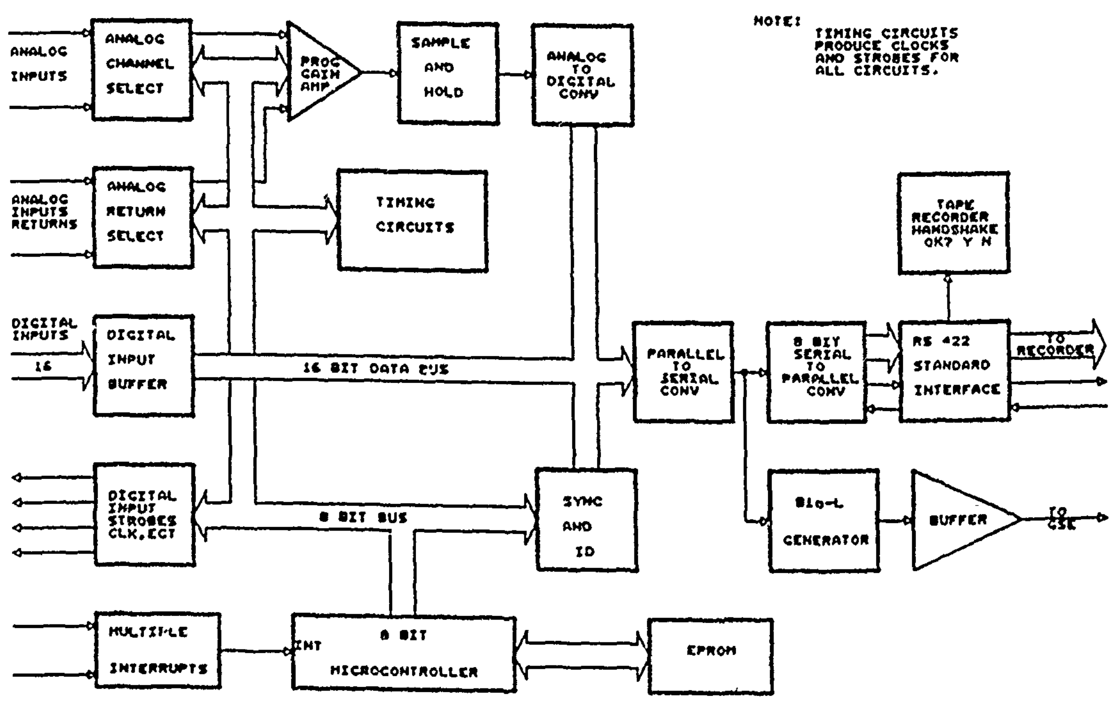


FIGURE 3.3.2 GAS PAYLOAD PCM ENCODER

the experiment mounted to the other side. This support system structure was designed at ERL.

3.3.2 Data Acquisition System

The Data Acquisition system in the GAS/VIPER was designed by ERL. It conditions, converts, and formats the payload data for recording. This system consists of two components. The Programmable PCM Encoder is shown in Fig. 3.3.2. The second component, designated the Electronics Box, provides the mission specific interface between the experiments and the Programmable PCM Encoder and must be tailored to the mission; a new box will be provided for each mission.

3.3.3 Data Recorder

A Sunstrand Data Logger, supplied as GFE, is used to store data in the GAS/VIPER system. It's capacity exceeds 300 Mbits. The data storage on the magnetic tape is performed in bursts from two internal 32 kbyte buffers. This process is transparent to the user. Therefore, the data may be transferred from the encoder to the recorder at any rate below a maximum as long as proper handshakes are observed.

3.3.4 Power Systems

The entire GAS payload support system is powered by a 28 volt, 50 ampere-hour silver-zinc battery. The power is distributed through 16 fused, independently switched five ampere circuits.

3.3.5 Current Status

It had been anticipated that the VIPER experiment would be flown during this contract period and a spare PCM encoder was fabricated and qualified. Electronics Research Laboratory staff completed the documentation and worked at AFGL to help their engineers bring their GSE into proper operating condition to support the GAS/VIPER program. Unfortunately, the Challenger mishap brought a slow-down in the shuttle flight program and any future activity will be carried out under the follow-on contract.

4.0 RESEARCH AND DEVELOPMENT PROGRAMS

4.1 Data Burst Study

4.1.1 Optical Recorders

A study to evaluate the suitability of using shuttle-qualified optical disk storage systems for data taken by a satellite when over remote auroral zones areas was undertaken. At the time the study was initiated definitive information was not available from AFGL personnel which would enable the total storage capacity needed in an optical recorder, or the intervals at which air-to-ground transmission can be accomplished, to be estimated. However, without the numbers which would be needed for the design for a specific program, it was still possible to evaluate the current state of the recording art and project the capability of optical recorders which will be available in the next few years. The study was completed in 1990 and the material which follows is taken from Quarterly Status Report No. 13 issued on 15 October 1990.

The data rate and the total storage capacity required in airborne recording systems continues to increase. At the present time magnetic tape recording remains the best choice for those applications which require very large capacity storage. The progress currently being made in increasing the recording density in magnetic media (which enables more bits of information to be packed per unit area) seems to indicate that magnetic storage will keep pace with the burgeoning need for high-rate, high-capacity storage devices. Tape recorders have their storage capacity limited only by the length of their tape, but are not well suited to selective recovery of recorded information (recovery must usually be made by playing the tape forward or backward until the area of interest is found). Magnetic disk recorders on the other hand have capacity limited by disk size but can be directed to speedily retrieve information from any specific location on the disk once the coordinates are specified.

Optical storage has become a very viable alternative to magnetic disk recording with the introduction of reliable optical disk recorders in which digital data is written onto a disk with a laser. Light weight, compact recorders are being developed for shuttle applications and should be airborne in 1991. At the present time[1], however, magnetic drives have the advantage from the standpoint of speed since their average access times run 28 ms or less while optical drives range form 35 to 95 ms. Faster, higher capacity recorders are under development and by the mid 90's rewritable, optical recorders should be compatible with magnetic disks.

Optical storage is not as sensitive as magnetic storage to magnetic and electrical fields and thus is a far better recording medium in an environment in which EMI is a problem. This fact makes it well suited for application in programs like BEAR and SPEAR. Furthermore, it is less sensitive to

---

[1] Chris Terry, "Drives Accept WORM and Rewritable Media", EDN, August 20, 1990, pg 95-100.

extremes in ambient temperature and humidity and, therefore, is a better medium for long term storage of data.

At the present time two types of optical disk recorders are available on the commercial market: those whose write process permanently alters the surface of the disk (write once) by using a laser beam to create a non-reversible pit, bubble or phase change on the disk surface, and those which employ the laser in an erasable process. The first type are referred to as WORM (Write-Once Read Multiple times) recorders while the second type are called EO (Erasable Optical) recorders.

4.1.1.1 <u>WORM Recorders</u>

As previously indicated WORM (Write-Once Read Multiple) recorders use a laser beam to write digital data by permanently altering the surface of the disk (frequently tellurium carbon) by creating a pit, bubble or phase change. Read is accomplished by detecting the light from the laser beam as it is reflected from the perturbations created on the surface by the write process. Disks are available in 5.25, 8, 12 and 24 inch diameters, single and double sided, with capacities reaching into the gigabytes per side. Approximately 45 companies[2] manufacture optical drives but relatively few have developed models for military applications. One of these, Mountain Optech Inc. of Boulder,

---

[2]Dave Bursky, "Optical Disk Drives Tackle All Needs", Electronic Design, October 26, 1989, pg 57-75.

Colorado, developed the 5.25 inch WORM recorder which Northeastern University's Electronics Research Laboratory has adapted for shuttle application in the CIV project.

4.1.1.1.1 <u>The CIV Recorder</u>

The Mountain Optech model SEL-2 WORM recorder is a ruggedized unit with a 5.25 inch, single sided, disk which has a storage capacity of 200 Mbytes. In this application it is driven through a SCSI interface and has a nominal data rate of 2.2 Mbps. In the CIV application data is written in bursts. Each burst usually contains 8 kbits of data and is written at an approximate rate of 250 kbs. A seek time of up to 475 ms is needed after a command has been issued for the beam to acquire some specified write location.

If the NASA/Sunstrand recorder described in the next section is proven flight worthy and becomes available then it would be superior because of its erasable feature. Our current plans are to incorporate this type of recorder in follow-on CIV missions.

4.1.1.2 <u>EO Recorder</u>

The disks used to store digital data in erasable optical (EO) recorders are constructed from different materials than those used in WORM recorders. The types which are currently available can employ dye polymers, a phase change material or a magneto-optic (MO) material. The latter is the most developed and commonly used and has the largest number of read-write cycles, about 10 million. All EO recorders under development for space and military application contain MO drives.

The MO drive recorder has a magnetic coil mounted on the optical head. The laser beam and the coil-produced magnetic field are directed at the desired spot on the disk. The laser heats the spot within the range of its Curie temperature and the magnetic polarization of the material is brought into agreement with the field. The read operation is carried out by sensing the magnetic polarity on each spot via reflection of the laser beam. The polarization of the reflected light is related to the magnetic polarization. This phenomenon is known as the Kerr Effect.

The MO recording/playback head is more elaborate, and therefore more costly, than those used in magnetic recorders. Furthermore, the entire MO disk must be erased before new data can be written. Erasure is carried out by heating the track with the laser as the disk rotates over a uni-directional magnetic field and thus restores the magnetic material to its pre-write polarization. (This is known as one-pass erasure.) Current research[3] is devoted to developing recorders which can write over previously written material, the process used in existing magnetic recorders. Two MO recorders under development show promise for shuttle borne applications and are discussed in the following sections.

---

[3]Many papers presented on this type of research at the Topical Conference on Optical Data Storage, March 5-7, 1990, Vancouver, Canada.

4.1.1.2.1 The NASA/Sunstrand EO Recorder

The Flight Systems Branch of NASA's Goddard Space Flight Center is currently testing[4] an EO recorder which was constructed for them by the Sunstrand Corp., Seattle, WA. This type of recorder was originally developed by SONY but Sunstrand has obtained a license to manufacture the recorder in the U.S. The Sunstrand unit has been extensively flight tested and NASA has modified a recorder to comply with its power requirements for shuttle application in the avionics package in the Hitchhiker program. The flight test is currently expected to take place in January 1991.

Future recorders will be U.S. made and will meet the 833 MIL Specification. The recorder has a capacity of 300 Mbytes. When driven through a SCSI interface a drive rate up to 1 Mbps is possible and a drive rate up to 10 Mbps is expected when an RS449 interface is used. The recording medium will be capable of removal. The bearings and the optical head are each hermetically sealed and a magnetic drive is employed so no outgassing is expected.

This recorder would be an excellent replacement for the Mountain Optech Model SEL-2 WORM recorder used in CIV. Since it is erasable it would not be necessary to replace the optical disk before flight, with the accompanying worry that the new disk may not perform reliably.

---

[4]Telephone conversation on April 24, 1990, with Dan Dalton, Branch Head, Flight Data Systems Branch, NASA Goddard Space Flight Center, Greenbelt, MD.

4.1.1.2.2 The GE Spacecraft Optical Disk Recorder (SODR)

General Electric is in the process of developing a Spacecraft Optical Disk Recorder[5] (SODR) under funding from NASA. It is anticipated that the development will be completed in the mid 90's. GE projects that the recorder will have a capacity of 10 Gbytes, be able to be driven at up to a 300 Mbps rate and be rewritable after a single-pass erasure. The recorder will employ a 14 inch diameter, double sided, optical disk. Nine laser beams are used -- one for tracking and 8 for data. Multitrack recording is carried out by first erasing the area to be written on in a single pass. The 8 tracks of data are then written simultaneously in a concentric swarth.

Detailed testing of the prototype unit was been carried out successfully at a drive rate of 133 Mbps during 1989.

4.2 Packet Telemetry Study

At the start of this contract it appeared that packet telemetry was going to be used with greater frequency for transmitting digital data from satellite and shuttle missions. At that time it was mandated for use in the IMPS program and it was felt that a study of its use, and potential use, in airborne applications should be undertaken.

The following material was first reported in Quarterly Status Report No. 3 dated 15 April 1988.

[5] Martin L. Levene, "High Performance Optical Disk Recorder -- Preliminary Test Results and Spaceflight Model Projections", Conference Digest, Topical Meeting on Optical Data Storage, Vancouver, Canada, March 5-7, 1990, pg 26-29.

4.2.1 Historical Perspective

Two basic forms of electrical communications developed with the advent of land line and radio networks. Telegraph systems broke their messages into packets (telegrams) and each packet was transmitted (routed) over dynamically assigned paths until the final destination was reached. The time delay encountered between the time of transmission and the time of reception at the final destination was a function of traffic density and routing. This dynamic-allocation of transmission bandwidth gave rise to efficient utilization of the channels between nodes in the network and messages were usually transmitted at the maximum allowable rate by automatic equipment. The telephone, telegraph and radio communication industries, on the other hand, used pre-allocation of bandwidth for the duration of a call, conversation or broadcast. The channel was tied up for the duration of the message and not utilized efficiently since the data rate was not matched to channel capacity and varied with the communicator.

The advent of computer technology made dynamic allocated communication systems feasible and economical. Computer switching could be employed at each node in a network and, with efficient routing, source-to-destination transmission could often be carried out in real time. A new communication technology, "packet switching", developed in which packets of digital data are moved at high speed from node-to-node in a network until the final destination is reached. Each packet includes digits which identify the sender, the destination and the data order numbers.

4.2.2 Space Applications

Packet networks employing radio links evolved and were soon recognized as having application for space communications. Packets of data originating in space craft, missiles, scientific probes and ground points can be relayed from satellite-to-satellite-to-ground-station and thence on to their final destinations over ground lines and microwave links. As we move into the 90's it is expected that packet telemetry systems will be used regularly to transmit data from space probes and shuttle-type vehicles to mainland US bases via NASA's Tracking and Data Relay Satellite System, TDRSS, which is currently being deployed. Military applications may use other dedicated satellites.

Packet radio telemetry units are associated with data sources and consist of a digital encoder/controller, radio transmitter and antenna. Airborne recorders are employed, when needed, to store data until the spacecraft is in the range of relay satellites or other vehicles. Satellite relay nodes consist of receivers, amplifiers, data multiplexers, controllers, transmitters and antennas.

The Consultative Committee for Space Data Systems (CCSDS) is an organization established by seven member agencies representing US, France, West Germany, India, Brazil and Japan. It has drawn up a number of non-binding recommendations and standards which member agencies can then put into service via memoranda of agreement. NASA is the agency which represents US and is enforcing certain standards in programs involving the shuttle such as IMPS.

Packet data structures are broken into 2 types: Source Packets and Transfer Frames. Source Packets can be thought of as the output from sensors. Groups of these packets are organized into Transfer Frames for transmission over radio links. Since errors are likely to occur in radio transmissions, Transfer Frames usually are encoded using Concatenated Reed-Solomon/Convolutional Coding. Error detecting codes are not required in Source Packets.

It is expected that AFGL will be involved with the formation of Source Packets. At present it appears that the formation of Transfer Frames and r-f transmission will be carried out by other agencies.

Source Packet formatting is treated in CCSDS Blue Book "Packet Telemetry", January 1987. Transfer Frame formatting is described in the Blue Book, but given more explicit treatment in CCSDS Blue Book "Telemetry Channel Coding", January, 1987. Rationale is covered in "Telemetry: Concept and Rationale", CCSDS 100.0G-1, Issue 1, Green Book, January, 1987. (All CCSDS books are available from NASA.)

4.2.3 Source Packet

Source Packets are comprised of a 48 bit header followed by an optional secondary header, the source data itself and finally an optional string of error control digits. Packet lengths are always integer multiples of 8 digits (1 octet) and can be as long as 8240 bit~. Two versions of source pockets are currently available. V :sion 1 is intended to handle most applications while Version 2 uses segmentation to break up long strings of data (typically from scanning instruments which generate thousands of bits in a single data scan) into packets containing fixed data lengths of 2048, 4096 or 8192 bits.

The primary header (48 bits) contains 16 bits for packet identification, 16 bits for sequence control and 16 bits to indicate the length of the following data stream.

The secondary header is optional, but when present always occurs in an integer multiple of octets (1 octet = 8 bits). It is used to indicate spacecraft time, data field format, spacecraft position, attitude and the like.

The user is given complete freedom in encoding the data into a bit stream. The only restriction, however, is that the total length of the data stream is an integer number of octets. Data formatting into this stream is something which should meet the approval of the ground data reduction facility.

Packet error detection control is optional and if used should employ an encoding polynomial which is agreed upon between the user and data reduction agency. At present it does not appear to be widely used.

4.2.4 Application to IMPS

Packet telemetry was employed in the IMPS shuttle program. Northeastern formatted the source data packets for storage on a tape recorder and for direct transmission. The packet format is shown in Table 4.2.4 and serves to illustrate the application in a specific program.

4.2.5 Search Techniques

A computer search was undertaken by the AFGL library for contract research under the key word packet. A number of recent contracts were abstracted but most were concerned with global transmission of data via packet systems under emergency, and often classified, conditions.

An excellent treatment of packet telemetry and its evolution can be obtained from the special issue on "Packet Radio Telemetry", Proc. IEEE, January, 1987.

It was found, however, that the NASA CCSDS Blue and Green Books referred to in Section 4.2.2 are more than adequate to cover AFGL applications in the foreseeable future.

TABLE 4.2.4

EIM

STORED DATA SOURCE PACKET

PRIMARY HEADER

BITS	CONTENTS	DESCRIPTION
0 - 15	0D1DH	PACKET ID
16 - 17	3H	SEGMENTATION FLAG
18 -31	XXXXH	SOURCE SEQUENCE COUNT
32 - 47	012FH	PACKET LENGTH

SECONDARY HEADER

BITS	CONTENTS	DESCRIPTION
48 - 55	FFH	DESTINATION: TR
56 - 63	01 - 14H	PACKET SEQUENCE 1 - 20
64 - 69	00 - 39 BCD	DAYS
70 - 75	00 - 23 BCD	HOURS
76 - 82	00 - 59 BCD	MINUTES
83 89	00 - 59 BCD	SECONDS
90 - 99	000 - 3E7H	MILLISECONDS
100 - 111	000H	NOT USED
112 - 123	061H	EIM ID FOR DHS
124 - 127	TBDH	NO. OF WORDS FOR AFT. DECK

SOURCE DATA

BITS	CONTENTS	DESCRIPTION
128 - 2527	300 - 8 BIT WORDS (1)	ESA - E/I DATA
2528 - 3575	131 - 8 BIT WORDS	PAF DATA
3576 - 4319	93 - 8 BIT WORDS	DIFP DATA
4320 - 4639	40 - 8 BIT WORKDS	SES DATA
4640 - 4807	21 - 8 BIT WORDS	QMS DATA
4808 - 4863	7 - 8 BIT WORDS (2)	PG DATA
4864 - 4879	2 - 8 BIT WORDS	EIS DATA
4880 - 4895	2 - 8 BIT WORDS	ONE'S COUNT

NOTES:
1. ESA DATA WORDS ARE INTERWEAVED; ESA-E FIRST.
2. FIVE PG 10 BIT WORDS ARE REARRANGED TO FORM THE SEVEN 8 BIT WORDS: 5 WORDS OF THE 8 MSB'S; 1 WORD OF 4 X 2 LSB'S IN SEQUENCE; 1 WORD OF 2 LSB'S OF WORD 5 IN MSB POSITION + 6 BITS.

4.3 Vibration Test Telemetry System

As an in-house work unit, a study was made for the selection and design of the components and circuitry which would be required for measurement of the vibration and shock experienced during the boost phase of a sounding rocket. The goal was to design, build, and test a totally self-contained system which could be placed on any desired test vehicle. Ideally it would have its own power source, transmitter and antenna.

The data acquisition system to condition, sample, digitize, and transmit these signals is shown in block form in Figure 4.3.1. The following parameters were chosen for the design of this test system:

Analog Inputs	- 8
Analog Level	- 0 to 5.0 volts
Accuracy	- up to 12 bits/sample
Sampling Rate	- up to 20,000 samples/sec
Programming	- EPROM controlled state machine
Power	- 28 volts, 10 watts
Size	- 4 x 6 x 1 inch

4.3.1 System Test

A test of the above system was conducted at the AFGL environmental test facility. The test consisted of monitoring the decommutated accelerometer outputs on strip charts and oscilloscopes and recording the data produced on magnetic tape for the following shake table levels:

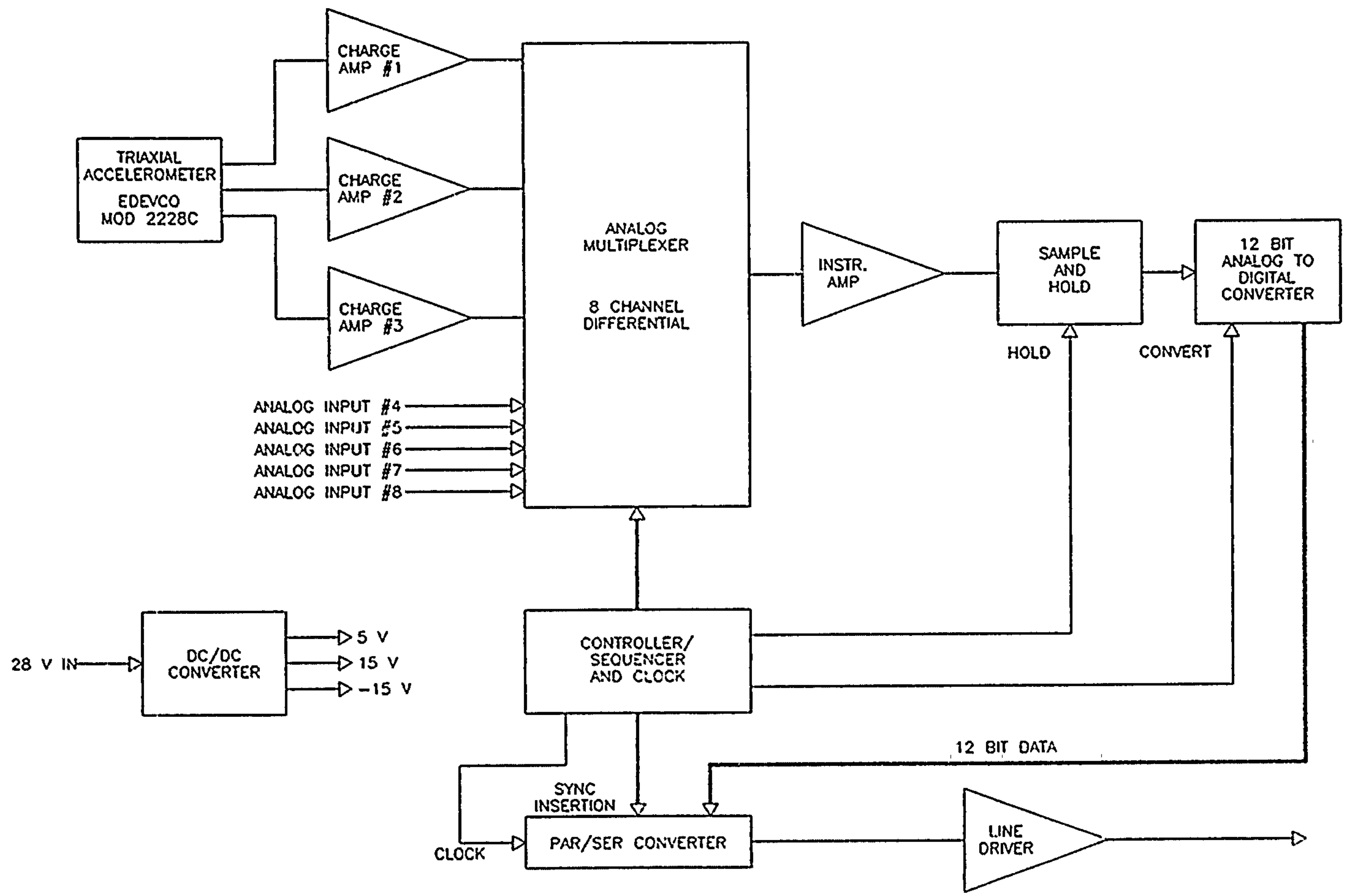


FIG. 4.3.1

VIBRATION TEST BLOCK DIAGRAM

1. Sine sweep from 20 to 2,000 Hz at a 10 G level

2. Sine sweep from 20 to 2,000 Hz at a 40 G level

3. Random noise at a 19.56 G level

Observation of these outputs indicated proper system operation at all times during the test. The recording on magnetic tape is available for further reduction if required.

4.4 Electro-Mechanical Release System

Pyrotechnic actuated mechanisms are used in a wide variety of sounding rocket applications. Investigation of alternatives led to the development of an electro-mechanical release system utilizing a solenoid. Reliability, testability, power consumption, overall size, ease of assembly and cost were primary design considerations. Eliminating the inherent problems of handling and testing explosive devices is also a significant factor.

The most common sounding rocket mechanism is the ejection of doors to expose or to allow deployment of sensors. Basic concepts of the proven pyrotechnic mechanisms were maintained and eventually a ball pin device was incorporated with a solenoid actuator. Figure 4.4 is an assembly of a door release mechanism indicating the solenoid block, solenoid, pivot arm and door block. The "quick-release" ball pin is the link between the payload mounted solenoid block and the ejectable door. Total weight of this assembly is 0.75 pounds. Operation of the mechanism is initiated by a pulse to the "push" type solenoid, actuating the pivot arm which in-turn imparts a force on the button of the ball pin, releasing the

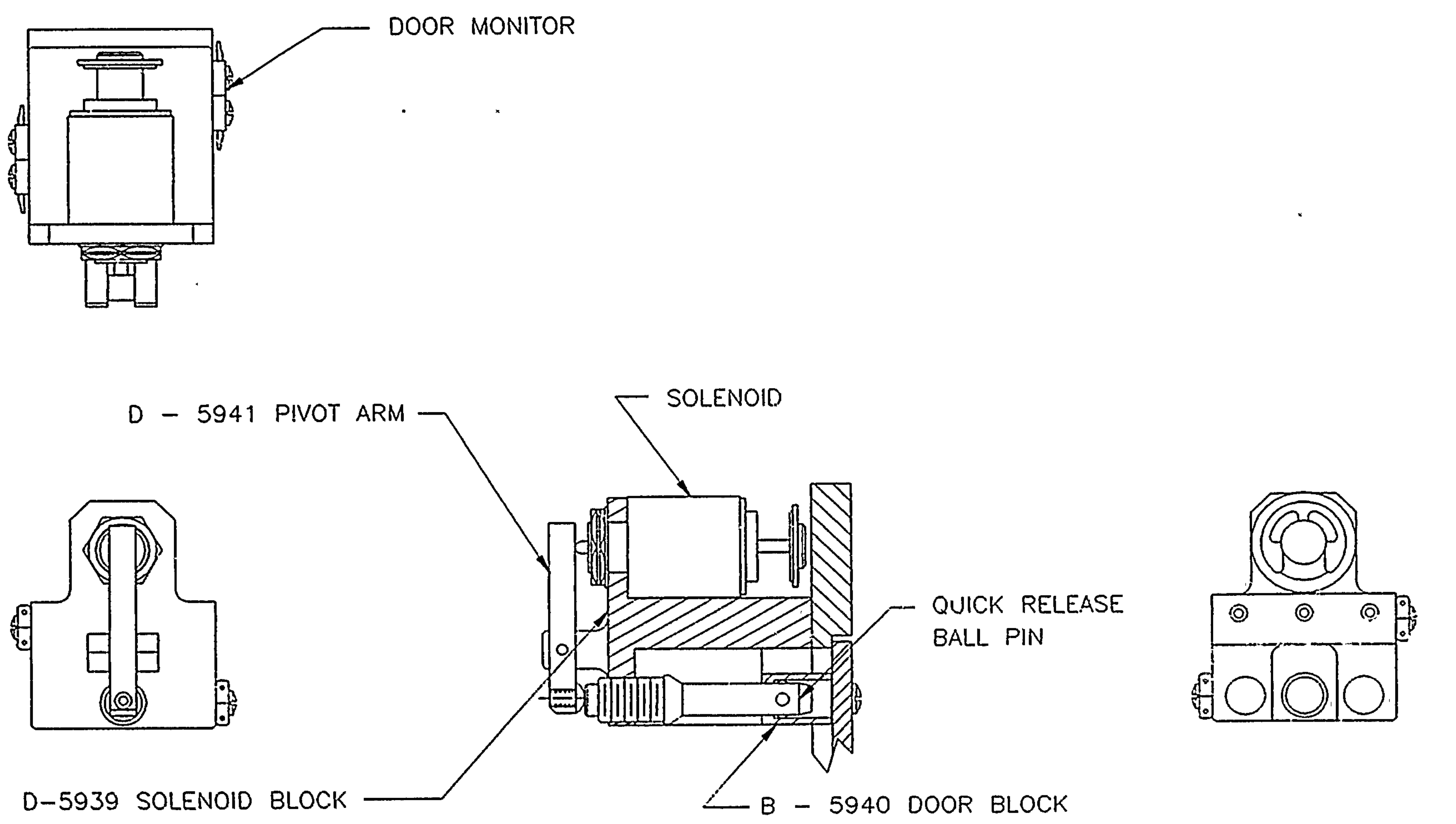


FIG. 4.4

DOOR EJECT MECHANISM

door block. Two springs are compressed between the solenoid block and the door block to drive the door away from the payload. The current design provides a total spring force of 20.7 pounds; however, other springs can be selected for specific applications.

A test fixture was designed and fabricated to empirically test the mechanism design and to gather test data. A series of fifty (50) evaluation tests were conducted with the initial assembly and test fixture to verify this concept and to identify potential problems. Only four failures occurred during this phase and they were attributable to alignment and/or assembly problems. Post test evaluation identified the reason for each of the failures, leading to modifications of the door block assembly. A new door block was fabricated to the proper tolerances and a series of thirty (30) tests were conducted. Normal assembly procedures were followed (on the test fixture) and a repeatable door eject was observed for each of the thirty tests. The test fixture mechanism was also subjected to vibration and shock tests. Acceptance levels were conducted first to evaluate the assembly prior to the qualification test. Three axis tests at both levels were followed by successful door ejects and an inspection of the mechanism.

In a payload application, the basic mechanism can be assembled prior to installation. The quick release pin should be adjusted to allow a small gap (0.003 to .005 inches) between the solenoid block and the door block when the springs are compressed. This gap insures that the quick release pin balls are not under tension. This procedure and the successful test program indicate that the concept of a solenoid actuated release mechanism is feasible. The next milestone would be a test of the mechanism on a future payload where space is available.

5.0 EVALUATION OF AFGL ROCKET SYSTEMS

The role of Northeastern personnel on some programs is to provide consultation and assistance to AFGL scientists in assuring that all data was telemetered using the best technology available. The payloads involved were integrated by industry and it was necessary to monitor the interfaces for and with the Air Force scientists. During this contract both the EXCEDE-III program and the SPIRIT-II program were in this category and are described in the following.

5.1 EXCEDE-III

The EXCEDE III program is a DNA funded experiment to measure the effects of energy deposition in space. The source of the energy is a high power electron gun which was launched from the north end of WSMR so that its trajectory could follow the magnetic field lines of the earth. The monitoring instrumentation was also launched on the same vehicle as the electron gun but was separated from the gun section at altitude. Onboard telemetry consisted of 2 television and 3 PCM r-f links. There was also an intervehicle ranging system and an uplink command and control system.

Part of AFGL's mission was to provide technical assistance to various phases of the EXCEDE III program. Northeastern University was assigned the task of attending design reviews and technical interchange meetings as consultants to the involved AFGL personnel and reporting any technical oversights or weaknesses in the area of telemetry, data acquisition and r-f transmission. A total of 4 formal conferences as well as several local informal meetings were attended.

In support of the same mission technical assistance was also provided to SIE by NU for the production of a document which would address the many flight readiness aspects of the EXCEDE-III program. Northeastern University was given responsibility for investigating the following topics:

1. Onboard Electrical Power - (batteries, dc to dc converters, distribution systems, fusing, charging, history).

2. Vehicle Tracking System - (redundancy, testing, changes since last use, EMC testing).

3. Uplink Command and Control - (history, test reports, interference).

4. System Safety - (grounding, lot acceptance tests and storage of explosive ordnance, safety plans, hazard levels, safety officer responsibilities, electromagnetic radiation hazards).

5. Intervehicle Ranging System - (hardware history, functional testing, redundancy, transponder certification, EMC testing).

6. Telemetry - (full specification of all link parameters, new developments, malfunction reports, redundancy, EMI and EMC tests, reliability analysis).

For each of the above topics, the personnel in charge of the specific system was contacted and asked to provide information, usually verbally, as to the history, documentation, testing, reliability, redundancy, spare parts, and design parameters of his system. Of particular importance was the existence of open action items which were initiated at readiness reviews. Information was also gleaned from the library of EXCEDE-III documents located at the SIE office at Hanscom Field.

This information was presented informally to SIE at several meetings and was followed up by a written report. This material was then combined with other topics that were investigated by SIE personnel and a formal report was presented to the appropriate EXCEDE-III project managers.

5.2 SPIRIT-II

The SPIRIT-II payload, a follow-on to SPIRIT-I is a Spectral Infrared Rocket Interferometer Telescoped experiment. It is a high spectral resolution earth limb rocket experiment designed to test auroral and airglow emission models in the longwave infrared. Northeastern participated in a Technical Interchange Meeting (TIM) at the Space Data Corp., Tempe, Arizona as a member of the review and evaluation team during the period November 2, 1987 to November 6, 1987. Personnel also attended a TIM at Rockwell International, Anaheim, California during the period of December 9, 1987 to December 12, 1987 to review the data handling systems for the Radiometer experiments.

The Critical Design Review (CDR) was held at the Center for Space Experiments, Utah State University during the period December 14, 1987 to December 18, 1987. Post CDR's were conducted at AFGL on 21 and 22 January 1988 and again at the Riverside Research Institute, Rossyln, Virginia on March 17, 1988 to review the telescopes for the Radiometers, the Focal Plane Baffle and the Cryogenic Systems.

Program delays were encountered and the SPIRIT-II program was then rescheduled for the FY92 period.

6.0 FIELD SUPPORT

This section contains a tabulation of those instances in which field programs required Northeastern personnel to provide professional and technician level support at field locations. In some instances the travel indicated was to launch ranges to install, test, and operate airborne equipment or provide ground support. In most instances travel was involved with conferences and meetings. In any event whenever overnight travel was undertaken the trip was classified as field support and is consequently listed.

PURPOSE OR LAUNCH DATE	LOCATION	VEHICLE TYPE & DESIGNATION	TRIP DURATION	STAFF
PDR	AFWL, NM	EXCEDE-III	7/7/87 to 7/10/87	Poirier
CDR	USU, UT	EXCEDE-III	8/4/87 to 8/6/87	Poirier
8/14/87	WFF, VA	COLDR-I	8/3/87 to 8/14/87	Anderson & Tracy
	WFF, VA	COLDR-I	8/9/87 to 8/14/87	Marks
PDR	SVC, CA	BEAR	8/10/87 to 8/14/87	Rochefort, Poirier & Morin
TIM	Analytyx, NH Fairchild,MD	IMPS	8/10/87 to 8/13/87	Sukys
TIM	MADC, NM	BEAR	9/29/87 to 9/30/87	O'Connor
TIM	SDC, AZ	EXCEDE-III	10/6/87 to 10/7/87	Poirier
TIM	Tucson, AZ	EXCEDE-III	10/20/87 to 10/22/87	Poirier
CONF.	San Diego,CA	ITC/USA	10/26/87 to 10/29/87	Rochefort & O'Connor

PURPOSE OR LAUNCH DATE	LOCATION	VEHICLE TYPE & DESIGNATION	TRIP DURATION	STAFF
TIM	SDC, AZ	SPIRIT-II	11/2/87 to 11/6/87	O'Connor
VACUUM TEST	Plumbrook Station, Sandusky,OH	SPEAR-I	11/3/87 to 11/6/87	Wheeler & Sweeney
TIM	SVC, MA	EXCEDE-III	12/9/87 to 12/10/87	Poirier
TIM	Rockwell, CA	SPIRIT-II	12/9/87 to 12/11/87	Sukys
12/13/87	WFF, VA	SPEAR-I	11/29/87 to 12/14/87	Wheeler & Sweeney
CDR	USU, UT	SPIRIT-II	12/14/87 to 12/18/87	O'Connor & Morin
TEST	JSC, TX	IBSS/AIS	1/26/88 to 1/29/88	Poirier
	JSC, TX	IBSS/AIS	2/7/88 to 2/11/88	Poirier
CDR	RRI, VA	IBSS/CIV	2/18/88	Sukys & Morin
CDR	SDC, AZ	EXCEDE-III	2/24/88 to 2/25/88	Poirier
POST-CDR	RRI, VA	SPIRIT-II	3/16/88 to 3/17/88	O'Connor & Morin
TIM	MADC, St. Louis	BEAR	4/6/88 to 4/8/88	Poirier & Tweed
ICD	JSC, TX	IBSS/CIV	5/18/88 to 5/19/88	Morin
ICD	LANL, NM	BEAR	6/13/88 to 6/16/88	Tweed
PDR	SVC, CA	BEAR	7/12/88 to 7/15/88	Poirier & Morin
TIM	LANL, NM	BEAR	7/27/88 to 7/30/88	Poirier
CDR	LANL, NM	BEAR	10/17/88 to 10/19/88	O'Connor, Poirier & Morin

PURPOSE OR LAUNCH DATE	LOCATION	VEHICLE TYPE & DESIGNATION	TRIP DURATION	STAFF
CONF.	Las Vegas, NV	ITC/USA	10/17/88 to 10/20/88	Sukys
TIM	WSMR, NM	BEAR	11/8/88 to 11/10/88	O'Connor
TEST	LANL, NM	BEAR	2/8/89 to 2/16/89	Poirier, Morin & Tweed
TEST	LANL, NM	BEAR	3/20/89 to 4/1/89 to 4/5/89	Poirier & Tweed Morin
TIM	Boeing, WA	LIFE	4/3/89 to 4/7/89	Sukys
TEST	LANL, NM	BEAR	3/27/89 to 4/6/89	Sweeney
TEST	LANL, NM	BEAR	3/29/89 to 4/6/89	O'Connor, Marks & Narkewich
TEST	WSMR, NM	BEAR	4/7/89 to 4/10/89	Marks & Narkewich
TEST	WSMR, NM	BEAR	4/10/89 to 5/27/89	Tweed
TEST	WSMR, NM	BEAR	4/13/89 to 4/20/89 to 4/26/89	Morin Poirier
TEST	WSMR, NM	BEAR	4/18/89 to 4/27/89	O'Connor
	WSMR, NM	BEAR	4/24/89 to 5/13/89	Marks
	WSMR, NM	BEAR	4/25/89 to 5/27/89	Narkewich
	WSMR, NM	BEAR	5/15/89 to 5/27/89	Poirier & Morin
	WSMR, NM	BEAR	5/17/89 to 5/27/89 to 6/15/89	O'Connor
TEST	WSMR, NM	BEAR	6/4/89 to 6/16/89	O'Connor, Poirier, Tweed & Narkewich

PURPOSE OR LAUNCH DATE	LOCATION	VEHICLE TYPE & DESIGNATION	TRIP DURATION	STAFF
TEST	WSMR, NM	BEAR	6/11/89 to 6/14/89	Rochefort
TEST	Boulder, CO	IBSS/CIV	6/19/89 to 6/22/89	Sukys
	Boulder, CO	IBSS/CIV	to 6/26/89	Whitehouse
TEST	WSMR, NM	BEAR	6/20/89 to 6/23/89	Poirier & Sweeney
TEST	WSMR, NM	BEAR	7/4/89 to 7/9/89	Marks
7/13/89	WSMR, NM	BEAR	7/5/89 to 7/15/89	O'Connor, Poirier, Sweeney, Tweed & Narkewich
	WSMR, NM	BEAR	7/7/89 to 7/14/89	Rochefort
			to 7/15/89	Morin
TIM	KAFB, NM	LIFE	7/5/89 to 7/7/89	Rochefort, Sukys & Morin
TIM	Boeing, WA	LIFE	8/16/89 to 8/18/89	Sukys & Morin
TIM	SDC, AZ	TM-II	9/6/89 to 9/14/89	Poirier
TIM	WSMR, NM	LIFE	9/18/89 to 9/21/89	Rochefort, O'Connor, Sukys, Morin & Anderson
TEST	WFF, VA	TM-II	9/26/89 to 10/11/89	Poirier
TIM	Bristol, Canada	LIFE	10/16/89 to 10/17/89	Morin & Anderson
CONF.	San Diego, CA	ITC/USA	10/30/89 11/3/89	Rochefort
TIM	AFSTC, NM	LIFE	12/4/89 to 12/6/89	Morin

PURPOSE OR LAUNCH DATE	LOCATION	VEHICLE TYPE & DESIGNATION	TRIP DURATION	STAFF
TEST	WFF, VA	TM-II	12/3/89 to 12/16/89	Poirier
TIM	Boeing, WA	LIFE	1/16/90 to 1/19/90	Morin & Anderson
1/30/90	WFF, VA	TM-II	1/22/90 to 1/31/90	Poirier
CONF.	Vancouver, Canada	DATA BURST	3/4/90 to 3/8/90	Rochefort
TIM	El Paso, TX & WSMR, NM	LIFE LIFE	4/30/90 to 5/3/90	Morin
TIM	Boeing, WA	LIFE	8/20/90 to 8/23/90	Morin
TEST	KSC, FL	IBSS/CIV	10/28/90 to 11/16/90 11/26/90 to 11/29/90	Whitehouse
TEST	KSC, FL	IBSS/CIV	12/17/90 to 12/19/90	Whitehouse

7.0 PERSONNEL

A list of the engineers, technicians and students who contributed to the work reported is given below:

J. Spencer Rochefort, Professor of Electrical and Computer Engineering, Laboratory Director and Principal Investigator.

Lawrence J. O'Connor, Senior Research Associate, Engineer and Co-Principal Investigator.

Raimundas J. Sukys, Senior Research Associate, Engineer.

Norman C. Poirier, Research Associate, Engineer.

Richard L. Morin, Research Associate, Engineer.

Thomas P. Wheeler, Research Assistant, Engineer.

Javier Azcue, Graduate Assistant.

David Poirier, Graduate Assistant.

S. Kim, Graduate Assistant.

Richard H. Marks, Electronic Technician - Telemetry and Evaluation.

Frederick J. Tracy, Electronic Technician - Instrumentation.

Charles B. Sweeney, Electrical Engineering Design Technician.

William R. Whitehouse, Electrical Engineering Design Technician.

Harry M. Tweed, Electronic Technician - Instrumentation.

Robert D. Anderson, Mechanical Designer-I.

Lawrence E. Narkewich, Mechanical Designer-II.

John Ignazio, Project Assistant - BSEE.

Johnathon Clifford, Project Assistant - BSEE.

Timothy Collins, Project Assistant - BSEE.

Souren Lefian, Project Assistant - BSEE.

John Oliva, Project Assistant - BSEE.

Eric Wiswall, Project Assistant - BSEE.

Anthony Bellia, Project Assistant - BET/EE.

James Chin, Project Assistant - BET/EE.

Mark DiCara, Project Assistant - BET/EE.

Manuel Goncalves, Project Assistant - BET/EE.

Christopher Madden, Project Assistant - BET/EE.

David Hoey, Project Assistant - BSME.

Donald Lee, Project Assistant - BSME.

Marc Levine, Project Assistant - BET/ME.

Fardin Sedghayar, Project Assistant - BET/ME.

Bobby Semple, Project Assistant - BET/ME.

8.0 RELATED CONTRACTS AND PUBLICATIONS

AF19(604)-3506	1 April 1958 through 30 June 1963.
AF19(628)-2433	1 April 1963 through 30 September 1966.
AF19(628)-4361	15 September 1964 through 31 March 1967.
AF19(628)-5140	1 April 1965 through 30 September 1968.
AF19628-67-C-0223	1 April 1967 through 28 February 1970.
AF19628-68-C-0197	1 April 1968 through 30 September 1971.
AF19628-70-C-0194	1 March 1970 through 28 February 1973.
AF19628-71-C-0030	1 April 1971 through 31 March 1974.
AF19628-73-C-0148	9 January 1973 through 30 April 1976.
AF19628-73-C-0152	1 March 1973 through 31 May 1976.
AF19628-76-C-0111	1 January 1976 through 30 November 1979.
AF19628-76-C-0152	1 May 1976 through 30 April 1981.
AF19628-80-C-0050	4 December 1979 through 3 December 1982.
AF19628-83-C-0037	4 December 1982 through 31 December 1986.
AF19628-81-C-0029	16 February 1981 through 5 May 1987.
AF19628-87-C-0128	15 July 1987 through present.